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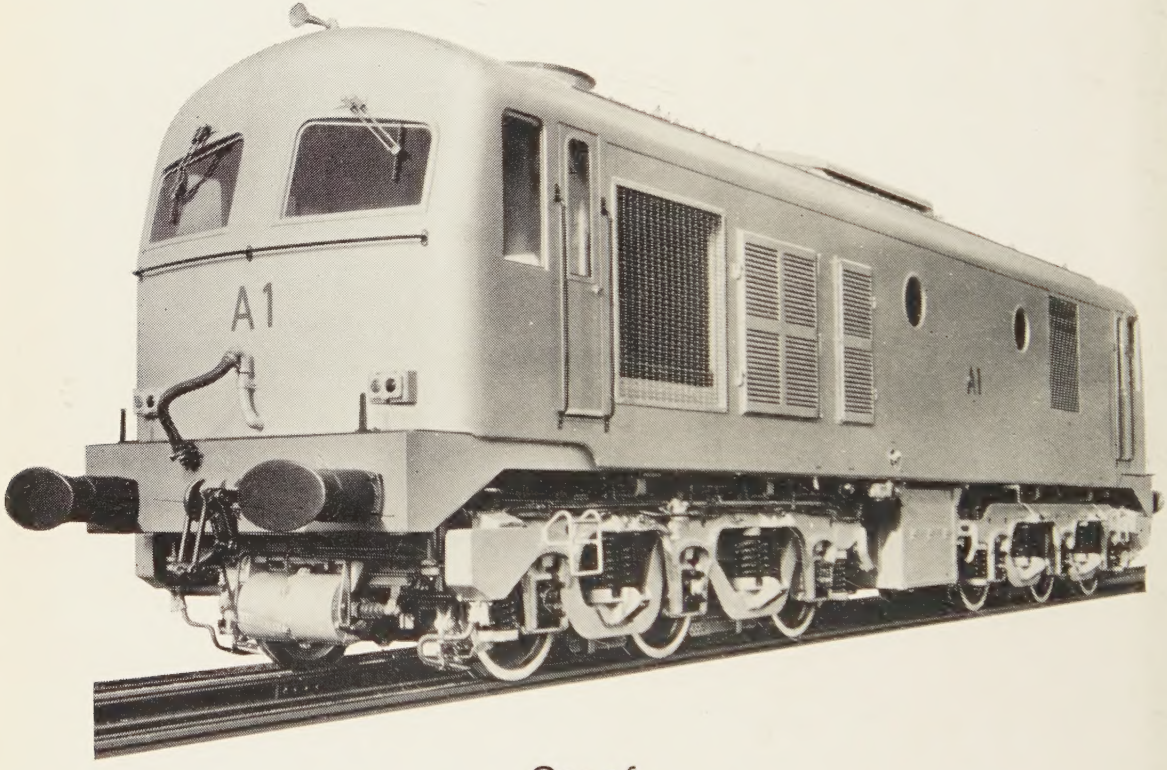

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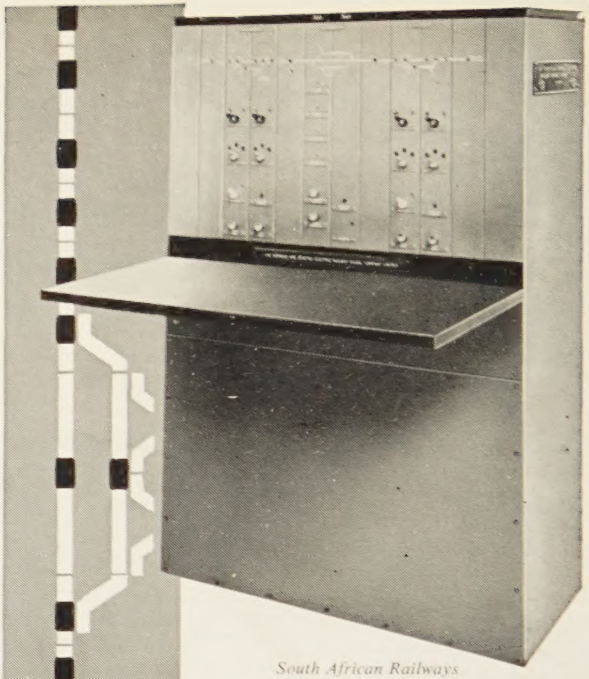

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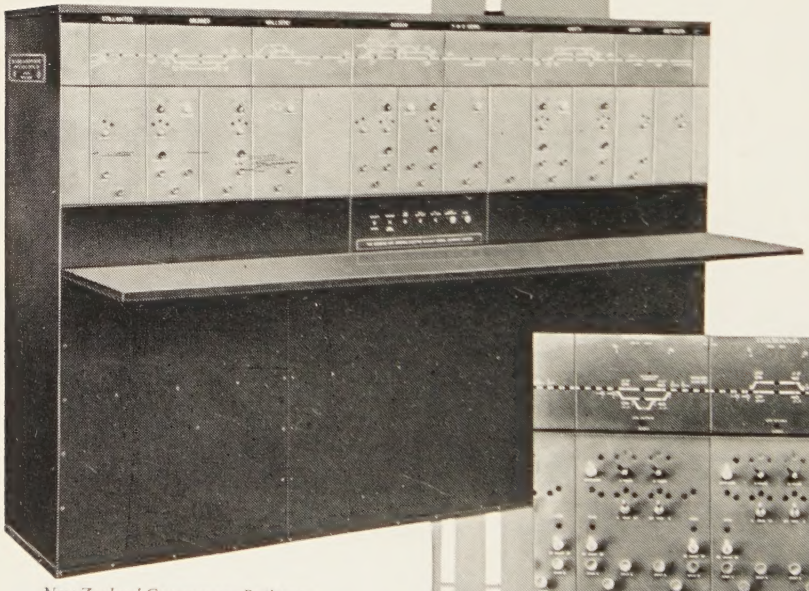

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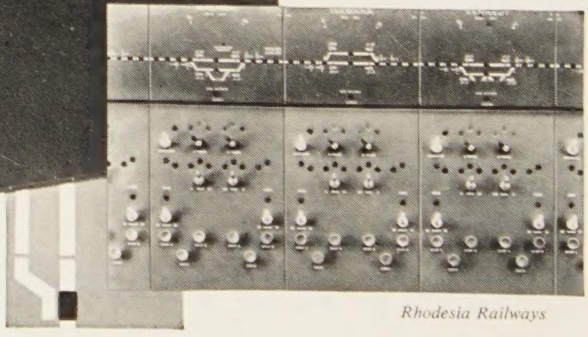

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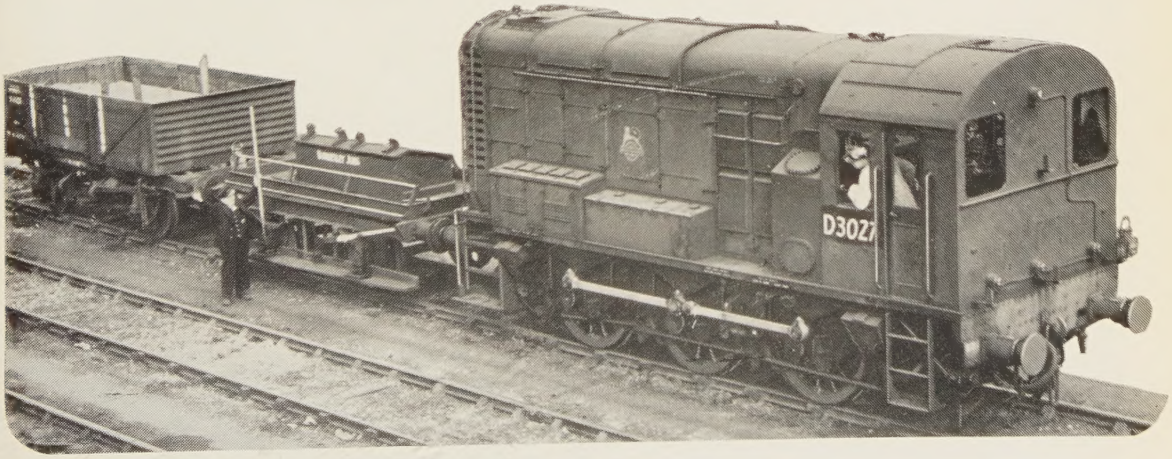

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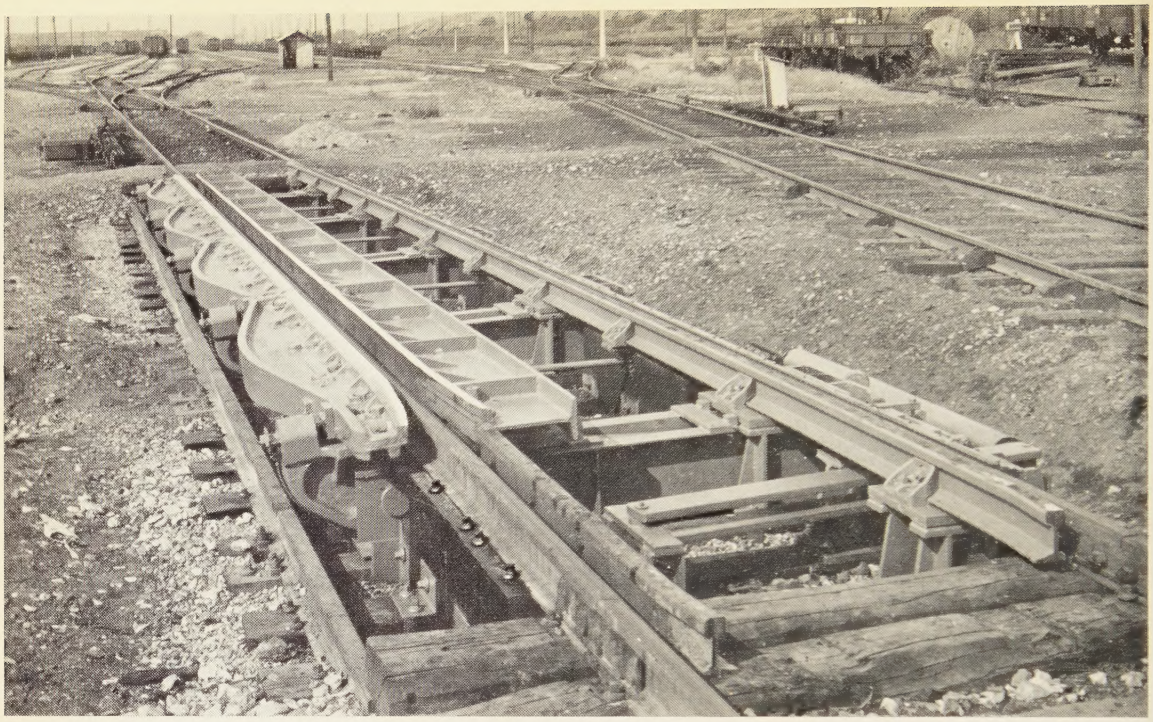

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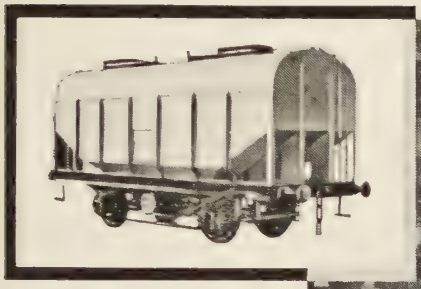

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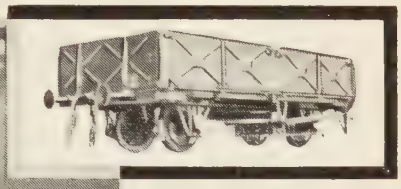

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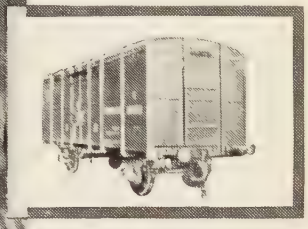

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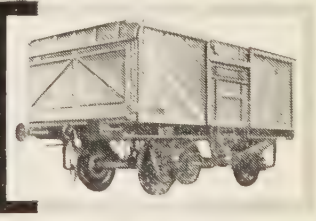

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BULLETIN
OF THE
INTERNATIONAL RAILWAY CONGRESS
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(ENGLISH EDITION)

[624 .2]

The beam on discrete elastic supports,

by J. P. ELLINGTON,
(Departments of Civil & Mechanical Engineering, University of Nottingham).

SUMMARY.

Expressions are obtained for the shear forces, moments and deflections of a uniform beam resting on discrete elastic supports spaced at equal intervals. Three different solutions are found, depending upon the relative magnitudes of the beam's flexural rigidity and the stiffness and spacing of the supports. Taking two of these solutions to a limit give known results for the beam on an elastic foundation or for the continuous beam on rigid supports, and suggests over what ranges these solutions are applicable. A numerical example is included to show the effect of a missing support.

1. Introduction.

In engineering practice many cases occur of the problem of a beam resting on discrete, equally spaced elastic supports. Girders on cross-beams, grids, etc., are found in ship, aircraft and constructional work, and there is the classical case of the rail resting on sleepers or ties. In many of these fields it is feasible to replace the separate supports by a continuous elastic supporting medium, this assumption allowing a wide range of solutions to be found, the most authoritative source being HETENYI's « Beams on Elastic Foundation » (1).

However, this assumption is not always valid, applying only to a limited range of support stiffness and spacing, (in certain cases of rails resting on sleepers embedded in concrete a better assumption is that of rigid supports). In other cases then recourse must be made to numerical solutions such as Southwell's relaxation method, or Hardy-Cross's moment distribution method. Alternatively, matrix methods can be used to derive sets of equations for solution by electronic digital computers (2).

In this paper an analytical solution is developed for the moments and deflections of a uniform beam resting on equal and equally spaced elastic supports by using the Calculus of Finite Differences. This problem has been previously examined by GOUGH (3) in connection with stresses in Railway Track, and more recently by MINKHORST (4), both authors showing that the bending moments at consecutive supports are related by geometric progressions. It was demonstrated in each case that two types of solution were possible, the ratios of these geometric series being either real or complex, but neither showed that there is a third solution corresponding to the transition from real to complex ratios.

It is not claimed that the present

solution is a complete answer to the permanent way designer's problems, but it is hoped that it will be of use in helping to assess errors when assumptions are made as to the elasticity and continuity of foundations or to the rigidity of supports.

2. The difference equations.

Consider now a long uniform beam, of modulus of elasticity E, and second moment of area I, resting on point supports which are spaced at equal distances L. The point supports are supposed to be perfectly elastic, and of stiffness such that a force k deflects them unit distance.

Taking a portion of the beam which is free of loading, the deflexion from the equilibrium position and the bending moment at the rth support will be y_r and M_r, and the slope at the ends of the element of beam between the rth and $(r + 1)$th supports will be :

$$\psi_r = (1/L)\,(y_{r+1} - y_r) - (L/6EI)(2M_r + M_{r+1})$$

and :

$$\psi_{r+1} = (1/L)\,(y_{r+1} - y_r) + (L/6EI)\,(2M_{r+1} + M_r) \qquad [1]$$

The shear force which is constant over the element is :

$$S_{r,r+1} = S_{r+1,r} = (1/L)(M_{r+1} - M_r) \qquad [2]$$

The positive directions for all quantities are as shown in Figure 1.

From equation [1], for continuity of the beam at the $(r+1)$th support :

$$\psi_{r+1} = (1/L)\,(y_{r+2} - y_{r+1}) - (L/6EI)\,(2\,M_{r+1} + M_{r+2})$$

$$= (1/L)\,(y_{r+1} - y_r) + (L/6EI)\,(2\,M_{r+1} + M_r)$$

and for equilibrium :

$$S_{r+1,r+2} - S_{r+1,r} + k y_{r+1} = (1/L)\,(M_{r+2} - 2\,M_{r+1} + M_r) + k y_{r+1} = 0$$

These latter two equations are a pair of homogeneous, second order, linear difference equations (5), in the unknowns

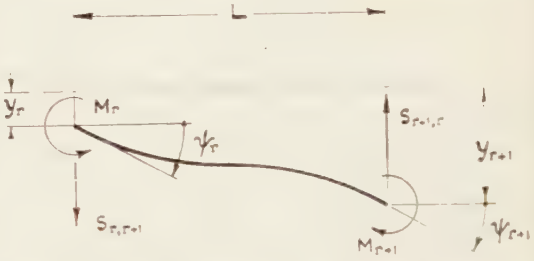

Fig. 1. — Sign convention for positive forces, couples and displacements.

y_r and M_r, and using the finite difference « shifting » operator **E**, defined by $\mathbf{E}^x y_r = y_{r+x}$, they may be written in operational form as :

$$(L^2/6EI)\,(\mathbf{E} - 1)^2\,M_r + (L^2/EI)\,\mathbf{E}M_r - (\mathbf{E} - 1)^2\,y_r = 0 \qquad [3]$$

and :

$$(\mathbf{E} - 1)^2\,M_r + kL\mathbf{E}y_r = 0 \qquad [4]$$

Equations [3] and [4] are similar to those derived by the author for the vibration of segmented beams (6), and in a different form, by BLEICH (7), for the buckling of a beam on elastic supports, and may be solved by assuming that :

$$M_r = A \exp(\Phi r),$$

and :

$$y_r = A\mu \exp(\Phi r) \qquad [5]$$

where A is a disposable constant and Φ and μ are to be determined. Noting that :

$$(E - 1)^2 \exp(\Phi r) = [\exp(\Phi) - 1]^2 \exp(\Phi r)$$

substitution in equation [4] gives :

$$\mu = -\frac{1}{kL} \cdot \frac{[\exp(\Phi) - 1]^2}{\exp(\Phi)}$$

$$= \frac{2}{kL}(1 - \cosh \Phi) \qquad [6]$$

Equation [3] then becomes :

$$\frac{L^2}{6EI}[\exp(\Phi) - 1]^2 + \frac{L^2}{EI}\exp(\Phi) - \mu[\exp(\Phi) - 1]^2 = 0$$

or :

$$\cosh^2\Phi - [2 - (kL^3/12EI)]\cosh\Phi + [1 + (kL^3/6EI)] = 0$$

Writing :

$$(kL^3/24EI) = K$$

$$\cosh \Phi_{1,2} = (1 - K) \pm \sqrt{(K^2 - 6K)} \qquad [7]$$

This is the characteristic equation giving a total of four roots, there being a positive and negative value Φ associated with each cosh Φ, whilst to each pair of roots there is a corresponding value of μ.

It can be seen that three forms of solution are possible depending on the value of K. When $K < 6$, the roots of equation [7] are complex, when $K > 6$, the roots are real and unequal, and when $K = 6$ the roots are real and equal.

3. Flexible supports $K < 6$.

When the parameter $K = (kL^3/24\ EI)$, is less than six the supports may be considered as relatively soft or flexible and the characteristic equation [7] becomes :

$$\cosh \Phi_{1,2} = a \pm ib \qquad [8]$$

where :

$$a = (1 - K)\ ,\ b = \sqrt{(6K - K^2)}$$

and :

$$i = \sqrt{(-1)}$$

The values of Φ corresponding to equation [8] are then :

$$\pm(\alpha + i\beta) \text{ and } \pm(\alpha - i\beta)$$

where :

$$\cosh \alpha \cos \beta = a \text{ , and } \sinh \alpha \sin \beta = b \qquad [9]$$

Squaring and adding both of these equations :

$$\cosh^2\alpha + \cos^2\beta = a^2 + b^2 + 1$$

then adding and subtracting, alternately :

$$2 \cosh \alpha \cos \beta = 2a$$

gives :

$$2\cosh\alpha = \sqrt{[(a+1)^2 + b^2]} + \sqrt{[(a-1)^2 + b^2]} = \sqrt{(4 + 2K)} + \sqrt{(6K)}$$

and : [10]

$$2\cos\beta = \sqrt{[(a+1)^2 + b^2]} - \sqrt{[(a-1)^2 + b^2]} = \sqrt{(4 + 2K)} - \sqrt{(6K)}$$

Returning now to equation [5] :

$$M_r = \Sigma A \exp(\Phi r)$$

$$= \exp(-\alpha r)[A_1 \sin \beta r + A_2 \cos \beta r] + \exp(\alpha r)[A_3 \sin \beta r + A_4 \cos \beta r] \qquad [11]$$

Also :

$$y_r = \Sigma A \mu \exp(\Phi r)$$

and :

$$\mu_{1,2} = \frac{2}{kL}(1 - \cosh \Phi) = \frac{2}{kL}(K - ib)$$

$$= \frac{2\sqrt{(6K)}}{kL}\exp(\mp \gamma)$$

where :

$$\gamma = \arctan(b/K) \qquad [12]$$

thus :

$$kLy_r/2\sqrt{(6K)} = \exp(-\alpha r)\,[A_1 \sin(\beta r + \gamma) + A_2 \cos(\beta r + \gamma)] + \exp(\alpha r)\,[A_3 \sin(\beta r - \gamma) + A_4 \cos(\beta r - \gamma)] \quad [13]$$

The values of α, β and γ calculated from equation [10] and [12] are shown in Figure 2, and it can be seen that for values of K up to about 0.20 α and β are equal. Below K values of say 0.05 γ is approximately equal to $\pi/2$, and it is in this range that the approximation of a uniform elastic foundation is applicable, the integral variable r being replaced by the continuous variable x/L. For the approximation to apply then the following inequality must be satisfied :

$$K < 0.05 \quad \text{or} : \quad kL^3/EI < 1.2$$

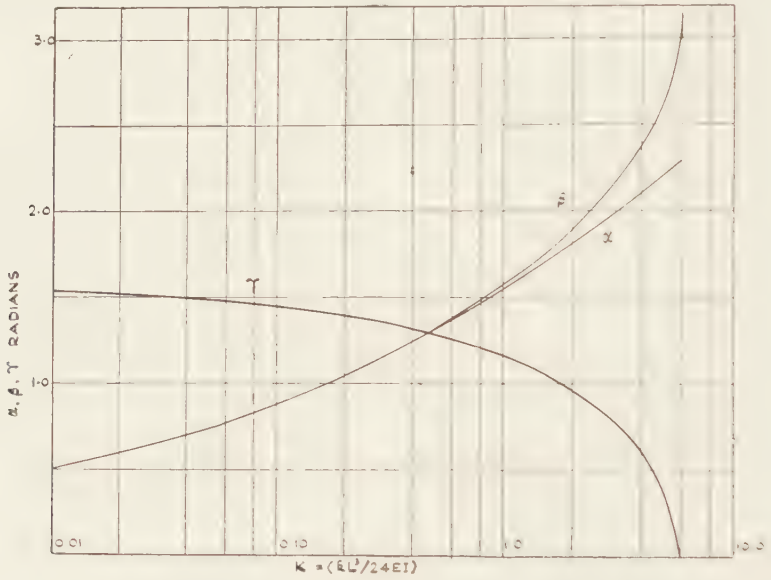

Fig. 2. — Characteristic angles α, β and γ for K less than six.

HETENYI advanced the rule that there should be at least four supports in the characteristic wave length $\pi L/\beta$, giving

$$kL^3\,EI < 1.5$$

4. Stiff supports K > 6.

Corresponding to a value of K greater than six the supports are relatively stiff or rigid, and the characteristic equation [7] shows that both values of cosh Φ are negative, consequently for a solution a change of variable is made :

$$\exp(\Phi) = -\exp(\theta) \quad [14]$$

Then :

$$\cosh \Phi = -\cosh \theta$$

so that :

$$\left.\begin{aligned} \mu_{1,2} &= (2/kL)\,(1 + \cosh \theta_{1,2}) \\ \text{where :} \\ \cosh \theta_{1,2} &= (K-1) \mp \sqrt{(K^2 - 6K)} \end{aligned}\right\} \quad [15]$$

Hence from equation [5] the bending moments and deflexions at the supports are given by :

$$M_r = (-1)^r [A_1 \exp(-\theta_1 r) + A_2 \exp(\theta_1 r) + A_3 \exp(-\theta_2 r) + A_4 \exp(\theta_2 r)] \quad [16]$$

and :

$$\frac{kLy_r}{2} = (-1)^r \{(1 + \cos\theta_1)[A_1 \exp(-\theta_1 r) + A_2 \exp(\theta_1 r)] + (1 + \cos\theta_2)[A_3 \exp(-\theta_2 r) + A_4 \exp(\theta_2 r)]\} \quad [17]$$

and a similar form of solution can be developed for the deflexions.

Figure 3 shows the variation of θ_1 and θ_2 with K, and it can be seen that θ_1 soon reaches its asymptotic value of 1.3169 or $\ln(2 + \sqrt{3})$. The values of θ_2 increase rapidly however, the values of $\exp(\theta_2 r)$ becoming overwhelmingly large as K and r are increased. Consequently as the deflexions and moments in the beam must remain finite then as K is increased the coefficient of $\exp(\theta_2 r)$ must decrease, and

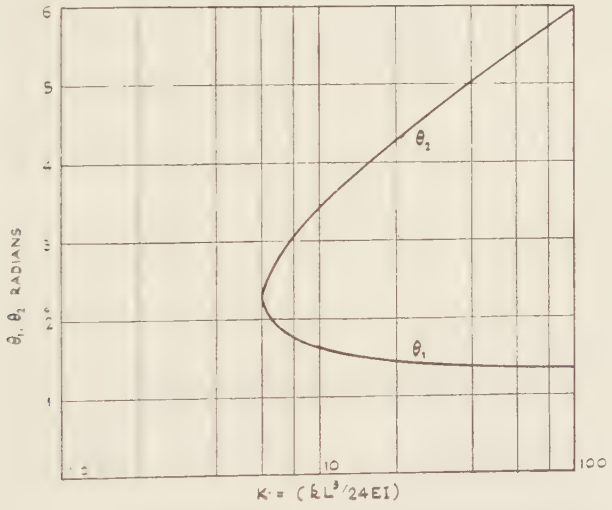

Fig. 3. — Characteristic angles θ_1 and θ_2 for K greater than six.

Alternatively, using the methods of the previous section, $\theta_{1,2}$ can be written as $(\alpha \pm \beta)$ where :

$$2\cosh\alpha = \sqrt{(6K)} + \sqrt{(2K + 4)}$$
$$2\cos\beta = \sqrt{(6K)} - \sqrt{(2K + 4)}$$

giving :

$$M_r = (-1)^r \{\exp(-\alpha r)[A_1 \sinh\beta r + A_2 \cosh\beta r] + \exp(\alpha r)[A_3 \sinh\beta r + A_4 \cosh\beta r]\} \quad [18]$$

above a certain value of K this coefficient can be expected to be zero. At the same time $\exp(-\theta_2 r)$ becomes negligibly small, and the remaining solution is that given by v. KARMAN and BIOT (8) for the support-moments of a uniform continuous beam resting on rigid supports. This solution would seem to apply for values of $K > 80$ say, or $kL^3/EI > 1900$.

5. Intermediate supports, K = 6.

When the parameter K equals six the characteristic equation [7] is seen to yield only one value of cosh Φ or two values of Φ, and thus only two, instead of the required, four solutions. Consequently, as in the theory of linear differential equations, the original assumed solution must be replaced by :

$$M_r = (-1)^r (A + Br) \exp(\theta r) \quad [19]$$

where $\cosh \theta = K - 1 = 5$.

Remembering that this equation has two roots $\pm \theta$, the general expression for the bending moments at the support is :

$$M_r = (-1)^r \{(A_1 + B_1 r) \exp(-\theta r) + (A_2 + B_2 r) \exp(\theta r)\} \quad [20]$$

Substitution in equation [4] shows that the support deflexions are :

$$kLy_r/2 = (-1)^r \{[6(A_1 + B_1 r) - \sqrt{(24)}B_1] \exp(-\theta r) + [6(A_2 + B_2 r) + \sqrt{(24)}B_2] \exp(\theta r)\} \quad [21]$$

6. The infinite beam.

When carrying out calculations using the equations outlined above much work can be saved by using the principle of superposition, and if necessary considering the loading in a single span only. This load can be further divided into symmetrical and reversely symmetrical components, allowing an immediate simplification. Since an infinitely long beam is considered the symmetry conditions allow attention to be restricted to the positive half of the beam. Then, as the deflexions and moments away from the load tend to zero, in the equations given previously all terms with exponentials having positive exponents must be zero thus leaving only two unknown constants to be determined.

Expressions can thus be derived for particular loading cases, but in general it seems simpler to substitute numerical values at the beginning of the problem, there being then two simple pairs of simultaneous equations to solve.

In practice the above simplification is not restricted to beams of infinite length but also applies to beams of such a length that the decaying exponentials reach a negligible value towards the end of the beam. This is influenced strongly by the stiffness of the beam and its supports, but a centrally loaded beam on 2N supports can be taken as infinite when say αN exceeds five or six.

7. The use of the equations.

To illustrate the use of the above equations the effect of a single concentrated load will be considered. Obviously the maximum bending moment in the beam will be reached when the load is at mid-span, and calculations will be set out below for this case.

(a) *K small.*

To consider a particular case relevant to railway practice is difficult due to the large variations found in the value of k, the stiffness of the supports. GOUGH (3) quotes figures of 20 000-40 000 lb./in., whilst HETENYI (1) gives values of 48 000-60 000 lb./in. Consequently, for convenience, a value of K = 0.0216 has been chosen, corresponding to a stiffness k of 40 000 lb./in., a span of 24 in., and a rail second moment of area of 35.6 in.^{4}

From equations [10] it can be seen that α and β are equal, having a value of 0.6, whilst from equation [12] γ is nearly equal to $\pi/2$. The arithmetic is rather simplified by the fact that α and β are equal since terms such as exp $(-\alpha r)$ sin αr may be read from existing tables (1).

Taking the origin for $r = 0$ as shown in Figure 4, CLAPEYRON's three-moments equation for the loaded and adjacent span may be written as :

$$5M_0 + M_1 + (6EI/L^2)(y_0 - y_1) = (3WL/8).$$

Taking moments about a support over the loaded span yields the equilibrium equation :

$$M_1 - M_0 + kLy_0 = (WL/2).$$

Using numerical values in equations [22] and then substituting in the above two equations gives :

$$0.375\ WL = 4.713\ A_1 + 8.309\ A_2$$
$$0.500\ WL = 1.030\ A_1 - 0.504\ A_2$$

Solving these simultaneous equations for A_1 and A_2 gives the following expression for the bending moment at the rth support :

$$M_r = \exp(-\alpha r)(0.397 \sin \alpha r - 0.180 \cos \alpha r)\ WL \qquad [22]$$

The resultant bending moment diagram is shown in Figure 4, where it can be

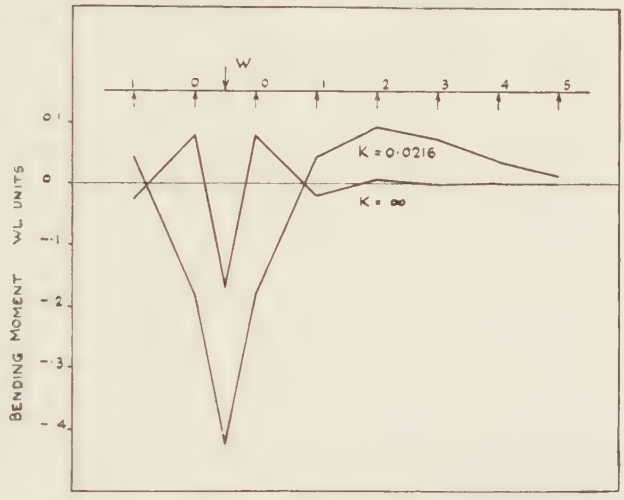

Fig. 4. — Bending moment diagram for load at mid-span.

seen that the maximum bending moment under the load is :

$$M_{max} = -1/4\ WL + M_0 = -0.430\ WL \qquad [23]$$

If the supports were imagined to be replaced by a continuous elastic foundation it can be readily shown that the maximum bending moment would be :

$$M'_{max} = -WL/4\,(6K)^{1/4} = -0.417\ WL$$

in other words the maximum bending moment would be underestimated by some 3 %.

(b) *K large.*

To go now to the other extreme an infinitely large value of K is chosen. This would seem to correspond to the case of the rail whose sleepers or ties are embedded in concrete, but the author does not have any actual values of stiffness, k, to substantiate this view.

Taking the same loading conditions as previously, and using the equations and discussion of sections (4) and (6) :

$$M_r = (-1)^r A \exp(-\theta r)$$

where :

$$\cosh\theta = 2 \text{ or } \exp(-\theta) = 2 - \sqrt{3} \qquad [24]$$

The three moments equation for the loaded and adjacent span is then :

$$5M_0 + M_1 = 3WL/8$$

Substituting and solving gives :

$$A = 3WL/8\ [5 - \exp(-\theta)]$$

or : [25]

$$M_r = (-1)^r (WL/16)(3 - \sqrt{3}) \exp(-\theta r)$$

The bending moment diagram is again shown in Figure 4, the maximum bending moment under the load being :

$$M_{max} = -1/4\ WL + M_0$$
$$= -(WL/16)(1 + \sqrt{3})$$
$$= -0.171\ WL. \qquad [26]$$

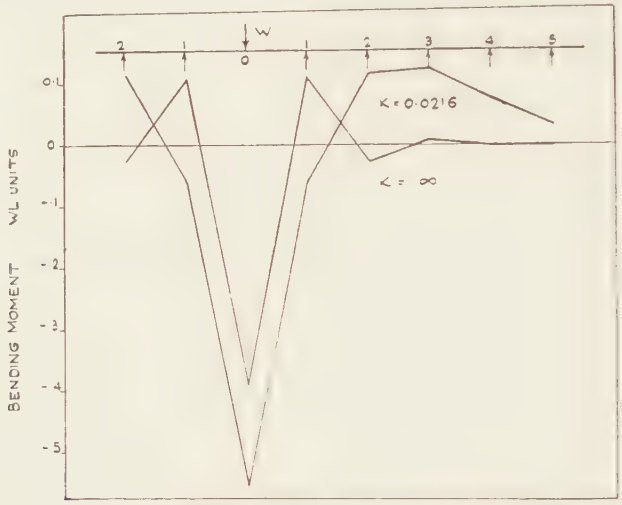

Fig. 5 — Bending moment diagram for load over a missing support.

8. A missing support.

Taking a single concentrated load on a beam with one support missing the more serious case of the load at the unsupported position will be examined. For comparison purposes the numerical values adopted in the previous section will again be used.

(a) *K small.*

Referring to Figure 5, the origin, $r = 0$, is taken at the load point which is above the missing support position. Then, by symmetry, the slope at the origin is zero, and from equation [1] :

$$\psi_0 = 0 = 2M_0 + M_1 + (6EI/L^2)(y_0 - y_1)$$

Also, taking moments, for equilibrium :

$$M_1 - M_0 = (WL/2)$$

Remembering K = 0.0216, with $\alpha = \beta = 0.6$, the resulting simultaneous equations are :

$$0 = 4.713\ A_1 + 5.309\ A_2$$

and :

$$0.5\ WL = 0.310\ A_1 - 0.547\ A_2$$

Solving these equations gives for the support moments :

$$M_r = \exp(-\alpha r)\ (0.627 \sin \alpha r - 0.557 \cos \alpha r)\ WL \qquad [27]$$

The bending moment diagram is shown in Figure 5, the value of the maximum bending moment now being :

$$M_{max} = M_0 = -0.557\ WL \qquad [28]$$

Comparing this value with equation [23], the effect of the missing support is to increase the maximum possible bending moment from — 0.430 WL to — 0.557 WL, an increase of 30 %.

(b) *K large.*

Whilst it is unlikely that supports will become loose and subside when on a concrete base, this case can be simply calculated as below.

The equilibrium equation is :

$$M_1 - M_0 = (WL/2)$$

giving :

$$A = -(WL/12)\ (3 + \sqrt{3}),$$

the support moments being :

$$M_r = (-1)^r\ (WL/12)\ (3 + \sqrt{3})\ \exp(-\theta r) \qquad [29]$$

The maximum bending moment, M_0, is :

$$M_{max} = -(WL/12)\ (3 + \sqrt{3}) = -0.394\ WL \qquad [30]$$

Thus, with rigid supports, the maximum possible bending moment is increased from — 0.171 WL to — 0.394 WL, a change of 130 %.

9. Conclusions.

Expressions are derived for the bending moments and deflexions at the supports of a beam resting on discrete equal elastic supports. It is shown that the approximation of a uniform continuous elastic foundation is reasonable whenever :

$$kL^3/EI < 1.2$$

and that the supports may be assumed to be rigid whenever :

$$kL^3/EI > 1.900.$$

A numerical example relevant to railway practice shows the increase in the maximum possible bending moment when a support is missing. For normal supports on ballast the increase is of the order of 30 %, whilst if the supports are rigid the increase is over 100 %.

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[62 (01 & 69]

Application of the theory of probability in the calculation of the strength of structures,

by Robert LÉVI,

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Justification of probability calculations.

The theory of probability is generally considered as a speculative science without practical importance. The very fact that it was established by drawing on examples from so-called games of chance (1) has contributed no little to the spread of this opinion.

To take probability into account, however, involves no artifice nor is it a vain occupation of the mind. On the contrary, it acts as a general antidote to the over-rigidity which all reasoning inevitably possesses. This can be shown by taking the application of probability theory to strength calculations as an example. All other applications which are being developed at present in very varied fields would serve equally well to demonstrate it.

In the construction of a bridge, the object is to obtain a strict assurance that its strength will not be inadequate during the whole period that it will be in service, no matter what loads will be applied to it. But this object comprises a contradiction.

The only method to ensure 100 % assurances would consist, in fact, in subjecting the bridge to the succession of loads which it will have to carry and meanwhile allowing the weather to produce its effects. But this method, assuming that it were possible, would in the case of failure only provide the required safety in the inverse sense and in the other case, it would only provide retrospective information. Such an experiment would conflict with its own object.

One must proceed, therefore, by the method of calculation and consequently admit that the resulting assurance will not be exactly 100 %.

Being obliged to be content with a quasi-certainty and not with absolute certainty, one is exposed to the conflicting factors of danger and inconvenience.

If the probability of failure tolerated for the projected work is too high, i.e. the risk being considerable, no one would build a bridge, for example, which had only 999 chances out of 1 000 of remaining intact. The residual chance of 1 in 1 000 is too high, on further reflexion, for it to be considered in the case of an eventuality which is seriously feared.

If, on the other hand, a chance of failure not exceeding one in a

(1) The first mathematical theory of probability was the work of MOIVRE who formulated the law, stated subsequently by LAPLACE, which was finally attributed to GAUSS : the theory concerned the game of tossing coins for heads or tails, or black and white balls.

million is demanded, this can be attained but only at a cost of a considerable quantity of material.

It is necessary, therefore, to study the acceptable rates of risk.

On this subject, we may quote an extract from a report by M. Marcel Prot, Inspector-General of Transport, at the Third Congress of the International Association of Bridges and Structures :

« To design an engineering structure « in such a way that failure is completely « impossible is to require the probability « of failure to be nil.

« Now, to require a nil chance of « failure is nonsense. It is in the nature « of things that certain risks must be « accepted. To seek a very high level of « safety in certain fields involves expen- « diture of time, money, work, and « materials which may entail, in conse- « quence, a reduction of safety in other « fields. This is all the more true as one « encounters in this subject, as in many « others, a law of diminishing returns « which makes an increase in safety more « and more costly as the level of safety « is itself increased.

« Experience shows that when the « probability of an accident is of the « order of one in a million, that prob- « ability is taken as practically nil, even « if that accident may cost us our lives. »

The principle that an extremely small risk of failure must be tolerated is now going to be assumed, without enlarging on the idea of varying the degree of safety according to the importanoe of the material and moral consequences should the risk materialize. We will study how the principle can be incorporated in the design of the projected structure.

All techniques invariably begin with the empirical method. Builders of bridges, as of cathedrals, have in the past learnt their trade by starting with proved models, modifying them according to their inspiration and then correcting or abandoning the new models if they appeared inadequate.

Even if there is no other more scientific method, such a development nevertheless leads to technical progress — in many fields this is the only method — but it is costly and dangerous. In any case, it provides no indication of the degree of safety obtained.

When it is proposed to build the same type of structure in large numbers, a better method consists of testing a sample (1) to destruction in order to obtain a measure of its total strength. The results always show a not inconsiderable amount of dispersion and this demonstrates the random nature of strength characteristics.

If the level of strength of a type of structure is variable, it means that the nature of strength is subject to random variations or, in other words, that chance intervenes.

Moreover, the intervention of chance must not be considered as the act of a superior power which could impair the law normally governing phenomena. Indeed, the previous argument is the sole cause of the anomaly.

In fact, when it was realised that it is impossible to test to destruction *the* bridge to be put into service, it was

(1) In probability terms, a sample intended to be representative of a « population » comprises a more or less large number of units (specimens).

decided to substitute *one* or *more* bridges of the same type. To substitute the general for the particular, however, is to commit an error because it assumes that one bridge is equivalent to another one.

It is convenient to group into one category all objects which appear superficially similar — as it is when making abstractions to fit a theory. But this diversity does not cease to exist just because one chooses to deny or ignore its existence. To speak of chance is a kind of refuge to excuse our own ignorance.

In addition to the variations of the supporting forces there are those of the stresses — the magnitude of live loads, the wind forces, the dead-weight itself — none of these elements are known precisely. The measuring instruments themselves are subject to error.

It is not possible, therefore, to assert that *the* true maximum overloads have been brought to bear, even if a trial has been carried out true to scale : all one can say is that *certain* values approaching them were used.

The variability of the mechanical qualities of materials and the variability of stresses are the main reasons which prevent the prediction of whether a bridge will have insufficient or superfluous strength. There are other reasons : bad workmanship, deterioration due to the weather, disturbance of the foundations, etc.

To this can be added the lack of precision in the calculations when it is necessary, on account of a change in method which is undoubtedly in the direction of progress and greater economy, to adopt the supporting force to the characteristics measured on test-pieces. The calculation is obviously indispensable in the case of work in hand for which trials on a large-scale basis would be too costly. In any case, it is thought reassuring for the mind but it engenders its own inherent defects.

Apart from errors contained in the principles forming the basis calculations, the latter comprise hypotheses which are more or less legitimate : the degree of embedding, uniformity of the assemblies, homogeneity of the materials — hypotheses which distort the results. Errors committed are, therefore, of two kinds : on the one hand, they are systematic but acting in an unknown manner; on the other hand, they are random in either one direction or the other.

It can be expected that the systematic errors may be reduced by a more refined analysis of the phenomena : the theorists concerned with structural analysis are following this up. But differences which are essentially random will always exist, being all the more important the more the work is neglected either in its conception, in the calculations of stability or in its construction.

Even the method based on small-scale models does not avoid such errors.

After all, the further one progresses from the purely empirical method which does not provide any information about the degree of safety obtained, the larger is the number of reliable links in the chain which connects the facts observed (quantitative tests of materials, admissible stresses, etc.).

There exist, however, links of a random character related to the dispersion of the quality of the materials and that of the

loads. The development of the science of estimation adds further links representing errors that the science cannot yet measure. Nevertheless, it is possible to consider these random links and to assign to them a range, i.e. a safety margin, according to the requirements of the case.

The concept of a « safety coefficient ».

Initially, the science of structural analysis considered Hooke's law as axiomatic, i.e. the proportionality at all points of the internal stresses to the strains and thus, to the external forces. This meant, in a way, that the « working stresses » — to use an obsolete term — or, as we say now, the « strains ». were below an admissible limit which itself was below the strain which leads to failure of the material. More recently, it has seemed preferable to increase the stresses and to compare the calculated strains with the breaking strains. This method of approach enables one to obtain the advantage which is to be expected from the theory of plasticity ([1]). Some authors even suggest combining underestimates of strains and over-estimates of stresses.

These adjustments made to the bases or results of the calculations are determined by coefficients : a coefficient reducing the breaking strain, a coefficient exaggerating the stresses, or both coefficients together. The justification for doing this, which is not generally stated precisely, is that the coefficients cover various uncertainties which affect the calculation. It matters little, moreover, whether the permitted strain is reduced to a quarter of that of the breaking strain, whether the stresses are quadrupled or whether the first is reduced by a half and the second is doubled simultaneously; it is the product of the coefficients employed alone that matters. It is this product, which can be called the safety coefficient, that must be divided into the ratio (non-homogeneous) of the admissible stresses to the breaking strain, such as it emerges from the strength calculations.

If the safety coefficients employed were varied according to the nature of the work, the type of materials and the lack of precision attaching to the loads, such a procedure would be legitimate. But it has become a habit to fix the safety coefficients arbitrarily, once and for all. In France, in comparing the calculated strain with the breaking strain, the value of 2 is used for metal (the conventional limit of elasticity being taken as the breaking strain), and 3.5 for concrete (the crushing strength measured on cubes of 20 cm [7.87 inches] side-length is taken as the breaking strain). If these rules have not proved harmful in the past, it should not be concluded that they are ideal.

It must be admitted, on the contrary, that a safety coefficient which has been shown to be at least sufficient for structures of below-average design or construction (inevitably there are some) and exposed to ill-defined live loads, must be too large when applied to structures which are known to be well designed, easy to construct and which are, in addition, called upon to carry well-defined loads. For example, it is absurd to adopt the

([1]) « Safety of Structures », by R. Lévi — 2nd Congress of the International Association of Bridges and Structures — Report I 6.

same coefficient for a road bridge as for an aqueduct. The probability that the live loads on the roads exceed their theoretical value by a half is not negligible, whereas it is not reasonable to expect the density of water to exceed 1.1.

On the other hand, one safety coefficient could not equally apply to structures made of different materials. The application of arbitrary coefficients involves distorsions which falsify economic comparisons which one may be encouraged to make, e.g. between metal and reinforced concrete. The development of new processes, such as prestressed concrete, sets a problem : at which rate should the coefficient be fixed to obtain sufficient safety without penalising or favouring it in relation to other competing processes?

The last example even shows that the principle of the « safety coefficient » is defective. In that part of a prestressed concrete girder which is subjected to tensile forces, there is a risk of the formation of large cracks in the concrete which theoretically remains under compression when carrying its working load. This risk, therefore, is large when compression, in the conditions of the calculation, is weak. In other words, the actual safety is the smaller the higher the so-called safety coefficient.

There is no doubt about the conclusion: the traditional safety coefficient is no more than a makeshift. In general, it is not very rational, sometimes it is frankly irrational.

Its arbitrary character is obvious to all and makes the designers a target of criticism which should really be addressed to those persons responsible for framing the regulations. « What! » exclaim the laymen, « you develop learned and abstruse calculations and when a precise answer has been obtained and expressed to two or three significant figures, you increase it by a coefficient which you fix at 2 or 3 or 4 according to inspiration or habits which you cannot justify in any way! What is the good of this pseudo-science, if you yourselves consider it necessary to alter its conclusions completely? » It is very certain that this criticism is justified and that it may make the designers themselves doubtful of the seriousness with which the study of their structures must be directed and controlled.

It would be very different with rules which were varied according to the circumstances and which would constantly remind the designers of the need for *good design and construction* in order to obtain a satisfactory degree of safety. Safety rules varied according to the type of construction, the variability of the characteristics of the materials and the care taken in actual construction would produce the tangible benefits that one can reasonably expect from precautions taken in good time.

Without hoping to achieve so much in the first instance, one can try first of all to substitute for the traditional safety coefficient a coefficient founded on reasoning and not on arbitrary rule or custom, in all cases where the carrying strength of a structure can be considered as proportional to the strength of one material, i.e. when failure is produced either by doubling the stresses or equally well by reducing the strength of the material by half (this is not a usual case according to the remarks made above about prestressed concrete).

Assume, therefore, that the manner in which a structure is exposed to failure is determined by a simple ratio. This may be the non-heterogeneous ratio of the value C measuring the stresses to the value R measuring its strength. One can also take the ratio between the strain P produced by the stresses and the breaking strain R : the numerator and the denominator are then expressed in the same units.

It must be noted, however, that if a critical value can be expressed by such a ratio, e. g. $\frac{P}{R} = 1$, the values inserted either in the denominator or the numerator must be related to real quantities, whereas one never has anything but estimated quantities and one knows that they are merely approximate, e.g. P_o, the strain calculated according to the maximum stresses in service and R_o, the strain regarded as the breaking strain. The problem at that point consists in fixing the ratio $\frac{P_o}{R_o}$ small enough so that there is only a very small probability ε that the true ratio $\frac{P}{R}$ is greater than unity.

It is necessary, therefore, to consider the dispersion of a ratio or a product (which is equivalent to the same thing) when the two terms are subject to random variations. One can, in effect, write :

$$\frac{P}{R} = \left(\frac{P}{P_o}\right) \cdot \left(\frac{R_o}{R}\right) \cdot \frac{P_o}{R_o}$$

and the two factors enclosed in brackets are random factors.

It is even possible to analyse this product into a larger number of factors. Thus, consider the ratio C/R :

$$\frac{\text{actual load}}{\text{real breaking strain}}$$

and attempt to tolerate only a small probability that it will reach the ratio $\frac{C_c}{R_c}$ of failure.

The calculations based on simplifying hypotheses, values of loads and breaking strains, etc., are expressed by a ratio :

$$\frac{C}{R} \quad \frac{\text{estimated value of load}}{\text{estimated value of breaking strain}}$$

One can proceed from this ratio to the one written above by means of multiplication.

$$\frac{C_c}{R_c} = \frac{C}{R} \times K_1 \times K_2 \times K_3 \times K_4$$

these factors being, for example :

$$K_1 = \frac{\text{actual load}}{\text{estimated value of load}}$$

$$K_2 = \frac{\text{actual strain under the action of a unit of stress}}{\text{strain attributed to the action of a unit of stress}}$$

$$K_3 = \frac{\text{average breaking strain of the material}}{\text{actual breaking strain of the piece}}$$

$$K_4 = \frac{\text{average breaking strain measured by tests}}{\text{average breaking strain of the material}}$$

These factors can themselves be decomposed into products of elementary factors. It is a question, therefore, of fixing a reasonable limit n to the product :

$$K_1 \times K_2 \times K_3 \times K_4 \times \ldots :$$

such that

$$\frac{\frac{C}{R}}{n} \quad \frac{n\,C}{R} \quad \frac{C_e}{R_e}$$

Hence, *for the safety coefficient to be valid, it must have a value* n *which the product of numerous error factors must not exceed, except for a probability* ε *set at a conveniently low value.*

Previously, the example of a chain was used to represent the difference between observed facts relating to stresses and to the quality of the materials, and it was added that random links exist which cannot be avoided in any circumstances. If one wishes to pursue this illustration, one can say that a large number of random links are involved, corresponding to these different factors.

Two questions arise. What scale should be adopted to indicate the margin required to cover this set of links? How are the respective ranges of successive links composed?

Overlapping of safety margins.

The second question will be answered first, dealing with the case where one or two random variables are added together or subtracted from each other (instead of being multiplied together as in the present case).

Suppose that an obstacle of dimension P, which is not well known, must be cleared with sufficient safety, without knowing precisely the length R of the jump, but with the knowledge that death will result in case of failure (fig. 1). First of all, one tries to measure the dispersion of R and P. By repeated trials without any load, one tries to measure their average values and the arithmetic or quadratic means of deviations from these average values.

Margins of safety (R-P)

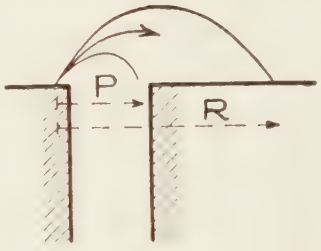


Fig. 1.

This accomplished, one can decide on the degree of safety required with respect of P and R.

Assume, for example, that a probability of failure of less than 1 in 10 000 is required and that the prolonged experience of the tests carried out to measure P and R has shown that in terms of the dispersion of P this probability corresponds to a difference of at least 0.45 m and that in terms of the dispersion of R it corresponds to a difference of 0.60 m. In that case, R would have to exceed P by 0.45 + 0.60 m = 1.05 m in order to warrant making the jump.

It is obvious, however, that the safety margin will be overgenerous. In fact, if the distance P is greater than the expected distance by 0.45 m — which could happen with a probability of 1 in 10 000 — it would require an extraordinary chance

for the distance R to be over-estimated at the same time by at least 0.60 m.

Abandoning this approach which is too simple by far, one can argue in the following manner which is inspired by the law of compound probabilities.

It is a fact that when two phenomena are independent of one another, the probability of two circumstances affecting each of the phenomena occurring simultaneously i.e. the « compound » probability, is the product of the probabilities of each circumstance taken in isolation. For example, if a coin is tossed twice in succession, the probability of a head being ½, the probability of getting heads both times is $\frac{1}{2} \times \frac{1}{2} = 1/4$.

Applying this law without due reflexion, certain authors believe that, in the case under consideration, it is necessary to extract the square-root of the required probability and to find a probability equal to this square-root for both P and R. Acting in this manner, one would obtain the difference of P and R from their means P_o and R_o which would occur once in a hundred times, e.g. 0.30 m and 0.40 m. The reasoning then consists of supposing that if the margin between the average values of the estimates of P and R is of 0.30 + 0.40 = 0.70 m, then the required safety is obtained.

This argument is erroneous. A total error of 0.70 m on R — P does not occur only when one of the errors is greater than 0.30 m and the other is greater than 0.40 m because, if the first is only of 0.25 m, the second can still be greater than 0.45 m or, the second being only of 0.30 m, the first can still be greater than 0.40 m.

Plot on a diagram the values of the differences $P - P_o$ and $R - R_o$, measuring them along two orthogonal axes and let the values of P and R be represented by points within small elementary areas whose densities are proportional to the probabilities (fig. 2). As it is a question of compound probability, the density varies proportionately in all the small strips parallel to the R axis, according to the function of R which is, in fact, the function of the probability of R : similarly for all the small strips parallel to the P axis, where the density varies proportionately to the function of the probability

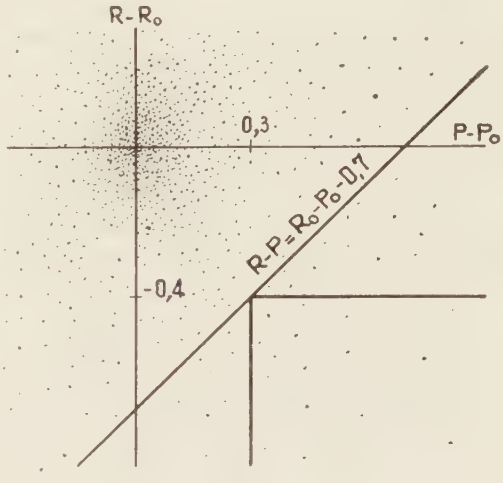


Fig. 2.

of P. The total mass thus distributed is equal to unity. To state that the probability of a positive difference of P greater than 0.30 m is equal to 1 in 100, is the equivalent of saying that the semi-plane to the right of 0.30 m on the abscissa contains a mass of 1/100 : similarly for the semi-plane situated below the ordinate of 0.40 m.

The result is, in effect, that the mass

comprised in the right-angle whose vertex has the co-ordinates 0.30 and — 0.40 is equal to 1/10 000. This angle, however, only covers a part of the semi-plane for which $P - P_o$ is greater $R - R_o$.

To reach the correct result, it is necessary to place a straight line at 45° to cut off a semi-plane occupied by a mass of 1/10 000. This straight line is obviously further from the origin than the vertex of the co-ordinates 0.30 and — 0.40. To calculate this it is necessary to integrate the surface without being restricted with respect to either P or R.

It is not possible to do this unless the probability function of both P and R is known. Fortunately a well-known property of the sum of squares enables a suitable approximation to be obtained.

Suppose, in fact, that it is sufficient to know the root mean square deviation of the random variables in order to estimate the smallest difference required to leave no more than the amount of residual probability fixed in advance.

Let δP and δR represent the differences from the arithmetic means, then the quadratic means can be obtained as follows:

$$P_o = \text{Av}(P) \qquad R_o = \text{Av}(R)$$

$$\text{hence} \begin{cases} \text{Av}(P - P_o) = \text{Av}(\delta P) = 0 \\ \text{Av}(R - R_o) = \text{Av}(\delta R) = 0 \end{cases}$$

$$\text{and} \begin{cases} \text{Av}(\delta P)^2 = \text{Av}(P - P_o)^2 \\ \text{Av}(\delta R)^2 = \text{Av}(R - R_o)^2 \end{cases}$$

Noting that :

$$\text{Av}(R - P) = \text{Av}(R_o - P_o + \delta R - \delta P) = \text{Av}(R) - \text{Av}(P)$$

and by forming the expressions

$$(R - P - R_o + P_o)^2 = (\delta R - \delta P)^2 = (\delta R)^2 + (\delta P)^2 - 2(\delta P \cdot \delta R),$$

it can be seen that by summing the squares, the double products contained in the last terms are as likely to be negative as positive and, in consequence, they cancel each other out in the general average.

Hence,

$$\text{Av}[\delta(R - P)]^2 = \text{Av}(\delta P)^2 + \text{Av}(\delta R)^2$$

This property of the quadratic mean extends over any number of component random variables. It shows an extraordinary peculiarity of the power of 2, the power which is also found in the law of LAPLACE-GAUSS (the Normal distribution) as well as in its characteristic function. The basic origin of this peculiarity, with its tremendous consequences, is still a mystery to mathematicians.

To return to the example above, it can be stated that the dispersion of P, that of R and that of R — P are proportional (see page 948) to 0.45, 0.60 and $\sqrt{0.45^2 + 0.60^2} = 0.75$. Consequently, the difference of R — P which exceeds that of $R_o - P_o$, with a probability of 1 in 10 000 is equal to 0.75 m (without appreciable error) instead of 1.05 m as given previously.

It can be said, therefore, that the links corresponding to the various random hazards overlap to a considerable extent. The dispersions combine together by merging into one another. The reduction is all the more pronounced the more large adjacent constituents there are. With four equal dispersions, the resulting dispersion is only twice as spread out.

Moreover, it can be noted that when one random variable has a small dispersion in relation to certain others, its effects on the total dispersion is negligible.

The reduction goes even further : it causes the irregularities in the constituent dispersions to disappear very rapidly (1).

On account of the last reason, one can assume without verification, in practice, that a random variable follows the law of Laplace-Gauss, if one can be certain that it is the result of several chance elements each with similar dispersions and that these elements can be combined *by addition*. Statistical tables then enable conclusions drawn from a relatively few number of tests to be extrapolated.

This is exactly what is required here because it is impossible to envisage the testing to destruction of 10 000 or 1 000 000 similar bridges before deciding if it is possible to put a few into service.

Utility of a logarithmic — normal law.

It is necessary now to return to the first question raised previously : what scale should be used to estimate the safety margin required?

To this question, the categoric answer is that all scales other than the logarithmic are absurd.

In order to demonstrate this, it is sufficient to examine the consequences resulting from the previous analysis, valid for sums of random variables, if it were applied without correction to the present problem.

Suppose, for the sake of argument, that the root mean square deviation of R — P estimated 30% of the average strength R_o of the material. Assuming, a priori, that the law of Laplace-Gauss applies to the numerical scale of the strains, one would limit the service strains to four or five times the root mean square deviation below R_o : this value would be negative. Even nil stresses would be dangerous!

It is known that when it is a matter of a small loss or profit, it makes little difference on which basis the percentage is calculated. To multiply a price by 1.01 or to divide it by 0.99 is approximately equivalent. It is a different matter when several percentages are added together : an increase of 90% (multiplication by 1.9) and a decrease of 90% (division by 10) are not equivalent.

On the other hand, the addition or substraction of the same amount in terms of logarithms increases or decreases a numerical quantity in the same proportion.

The substitution of a logarithmic scale for an arithmetic one is required, therefore, for better understanding whenever the relationships between dimensions under consideration are in terms of proportions. This substitution is often

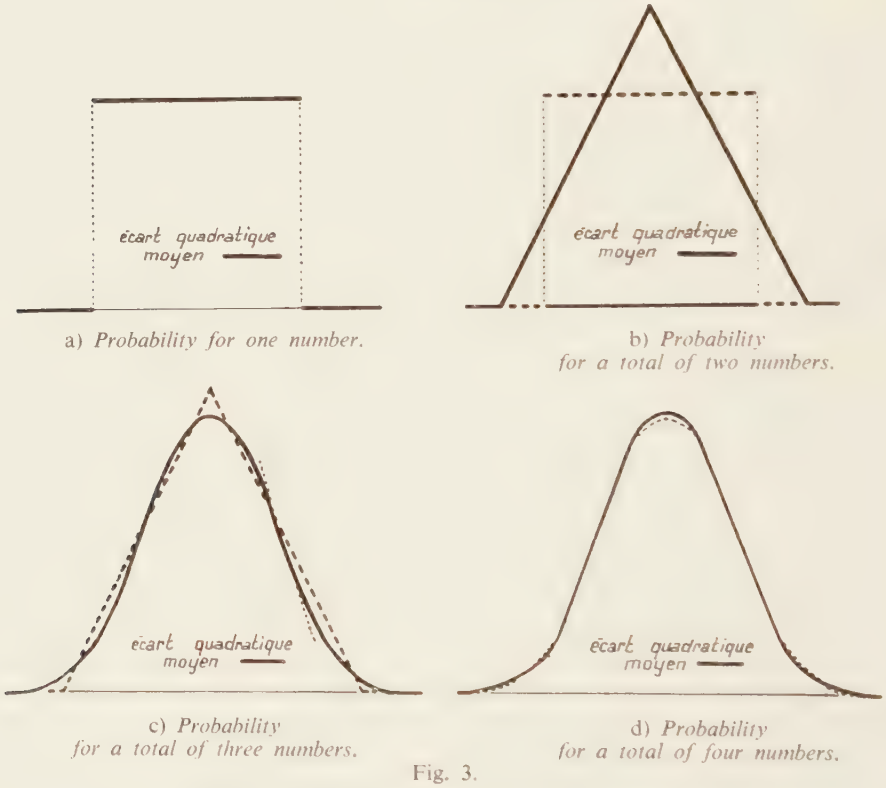
(1) Consider, for example, the case where each of the random variables is determined by a uniform probability from — 1/2 to 1/2 and ceases abruptly at these values, as in the error committed in rounding a decimal number to a whole number. In the diagram used previously for the sum of two random variables, the probability density is uniform on a square : cutting the diagram with parallel straight lines on the diagonal of the square, and not parallel to one of the sides, avoids the probability of the total having discontinuities of the first kind, as have the constituent probabilities. Discontinuities exist of the second kind, which are also superceded by discontinuities of the third kind when a third random variable is added, and so on. The smoothing process continues rapidly, as can be seen by superimposing various curves, drawn with suitable scales. As soon as it is a question of four variables, with dispersions of a similar spread, their sum follows almost exactly an asymptotic law which is no other than the law of Laplace-Gauss (normal distribution). (fig. 3.)

carried out in the most varied of fields : thermodynamics, acoustics, telecommunications, etc... Why not do as much in the field of structures, precisely where the relationships between several units of measurement must be considered?

values A_o and B_o, and the differences from the respective means δA and δB. Forming the products AB in order to calculate the mean values, one obtains :

$$AB = (A_o + \delta A)(B_o + \delta B)$$
$$= A_oB_o + A_o \cdot \delta B + B_o \cdot \delta A + \delta A \cdot \delta B$$

Errors resulting from the rounding of decimal numbers.



a) *Probability for one number.*

b) *Probability for a total of two numbers.*

c) *Probability for a total of three numbers.*

d) *Probability for a total of four numbers.*

Fig. 3.

N. B. — Ecart quadratique moyen. = root mean square deviation.

A clearer understanding will be obtained by returning to the same reasoning used previously, but applying it to the *products* of random variables instead of *additions*.

Consider the product of two K factors into which the « safety coefficient » can be decomposed. Let the two random variables be called A and B, their average

from which, for the same reason as previously (page 950) in connexion with the mean average of sums :

$$\text{Av. (AB)} = \text{Av. (A)}. \text{ Mean (B)}.$$

But similar results are not obtained when considering differences of AB from the average A_oB_o.

In fact, these differences can be written as :

$$(AB - A_oB_o)^2 = (A_o \cdot \delta B + B_o \cdot \delta A + \delta A \cdot \delta B)^2$$

$$= A_o^2 B_o^2 \left[\left(\frac{\delta B}{B_o}\right)^2 + \left(\frac{\delta A}{A_o}\right)^2 + 2\,\frac{\delta A \cdot \delta B}{A_o B_o} + \ldots + \left(\frac{\delta A}{A_o}\right)^2 \cdot \left(\frac{\delta B}{B_o}\right)^2\right]$$

hence

$$\mathrm{Av}\left(\frac{AB}{A_oB_o} - 1\right)^2 = \mathrm{Av}\left(\frac{AB - A_oB_o}{A_oB_o}\right)^2$$

$$= \mathrm{Av}\left(\frac{\delta A}{A_o}\right)^2 + \mathrm{Av}\left(\frac{\delta B}{B_o}\right)^2 + \mathrm{Av}\left[\left(\frac{\delta A}{A_o}\right)^2\left(\frac{\delta B}{B_o}\right)^2\right]$$

The squares of the mean relative differences can only be added together as a first approximation on account of the presence of the last term where the squares of relative differences are multiplied together.

In addition, one obtains a clear indication of the asymmetry of the dispersion of AB values.

These approximations to simple laws which govern the addition of random variables increase when one is dealing with a number of factors subject to random variations, such as the quantity being investigated, i.e. $K_1K_2K_3K_4 \ldots$

Every thing is correct, however, if instead of considering quantities such as A and B, their logarithms are taken and the differences of these values are taken from the mean of the logarithms. In particular, one obtains :

$$\mathrm{Av}\ [\delta(\log.\ AB)]^2 = \mathrm{Av}\ [\delta(\log.\ A)]^2 + \mathrm{Av}\ [\delta\,(\log.\ B)]^2 = \alpha^2 + \beta^2$$

The Greek letters are used here to indicate the quadratic means of differences expressed in logarithms.

This property can be generalised to apply to any number of random factors and, as before, with every multiplication the probability curve tends towards that of the normal curve, when the logarithm of the product is taken as the variable.

Thus, two conclusions are reached concerning the product $K_1K_2K_3K_4 \ldots$ considered previously, as follows :

1) The logarithm of the product $K_1K_2K_3K_4$ which is the sum of the logarithms of K_1, K_2, K_3, K_4 has a root mean square deviation equal to the quadratic sum σ of the means α_1, α_2, α_3, α_4, etc., of the logarithmic deviations (when these deviations are small, they can be replaced by relative deviations) :

$$\sigma^2 = \alpha_1^2 + \alpha_2^2 + \alpha_3^2 + \alpha_4^2 + \ldots$$

2) The LAPLACE-GAUSS law applies to the logarithm of $K_1K_2K_3K_4$. As the average values of log. K_1, log. K_2, etc., are nil if K_1, K_2, etc., have been correctly defined, the reasonable limit n to fix for $K_1K_2K_3K_4$ is obtained by extracting from statistical tables the number n of root mean square deviations for which the residual probability is ε, where

$$\int_{n}^{\infty} e^{-\frac{x^2}{2}} \frac{dx}{\sqrt{2\pi}} = \varepsilon$$

and multiplying the root mean square deviation by this number — this gives log. n corresponding to the solution of the problem — and then taking the exponential of the product $\eta\sigma$

$$n = e^{\eta\sigma}$$

It might be objected that this derivation assumes that the primary dispersions of log. K_1, log. K_2, etc., are numerous without a minority of predominant ones, or that the latter are normally distributed.

This criticism is hardly well-founded. The most that must be admitted is that the dispersions of stresses combine together by addition and not by multiplication. In general, however, there is one kind of stress that is predominant and in this case there is no reason to concede that it does not conform with the logaritmic-normal law, i.e. the normal distribution of probability applied to the logarithms of random variables.

In the case of stresses of a single type, of the distribution of stresses in the constituent materials, and in the case of the strength of the materials, it is possible to show, in fact, that all anomalies, all errors of estimation, all irregularities can be expressed as raising or reducing factors which can either be multiplied together or divided one by another.

Simple applications.

A careful examination of the problem has definitely shown that the theory of probability allows a rational estimate to be made of the margin which it is necessary to respect in order to obtain the degree of safety judged suitable. Moreover, when the conditions of failure are expressed by a critical value of a *ratio* — a ratio between the size of the stresses and the strength of the material — this margin can be established in a simple manner by the use of logarithms.

This ratio can be expressed as a product of random factors. In the case of each one of them it is necessary to measure or estimate the root mean square deviation of the logarithmic difference from the mean of the logarithms, which can often be replaced by the root mean square deviation in percentage form. The quadratic total σ of these average differences α_1, α_2, α_3, etc., gives the root mean square deviation of the relationship in question

$$\sigma^2 = \alpha_1^2 + \alpha_2^2 + \alpha_3^2 + \alpha_4^2 + \ldots$$

If the probability ε of failure which is tolerated remains always the same, the value of η is determined once and for all. It is sufficient then to multiply η by σ and to raise the product to the power of e, the base of Naperian logarithms. Thus is obtained the value of η which the raising factor, due to various random chances, is likely to exceed with a probability of ε :

$$n = e^{\eta\sigma} = \text{total random ratio.}$$

This number can then be taken as a safety coefficient, either to divide into the breaking strain or to multiply the normal stresses.

It should be noted that by « normal stresses » is meant the normal values of the stresses under consideration which are the most dangerous ones to be expected during the anticipated service life.

Such a calculation, simple in spite of appearances, requires extensive preliminary experimentation and research. There is no

question, therefore, of repeating it for each piece of work. On the other hand, it should be impressed on those responsible for safety regulations.

Equally there is justification for carrying out a special safety calculation at the time when a large structure is being designed. The discussion about the various hazards to which the work will be subjected suggests at the same time that they be measured in order to limit them by structural arrangements. Having a more precise appreciation of the risks and estimating their correct values better, one can then introduce dispersions adapted to the case under study. A considerable saving in the quantities of materials used should then be achieved.

These safety calculations must be made to take account of all the factors of insecurity or error, but the results must in no way be amended later. Too often, the usually employed safety coefficient is increased anyhow and without reason. This has led to really absurd rules. By replacing a coefficient of 3 which is largely sufficient for metal framework by a coefficient of 5, it is thought perhaps that safety is increased in the ratio of 3 to 5. Statistical tables show that if the chance of failure was one in an million with a coefficient of 3, it can no longer be expressed but in terms of millionths of one in a thousand-million with a coefficient of 5, i.e. the risk of a single accident would not be measurable even after a lapse of time of several million years The requirement has therefore been greatly exceeded.

The first example will be of a railway bridge carefully constructed in steel of 42 kg/mm^2 and of medium length. The numerical values employed are not, of course, definite in character and are only simple estimates.

a) *For the main trellis girders*, the breaking strain is the limit of elasticity with a normal value of 26 kg/mm^2 and a root mean square deviation of $\alpha_1 = 6\%$. For the normal live-load, the dynamic effects are negligible, but the normal load may exceed by 10% the total permanent load + the live-load of a standard train, with a root mean square deviation of $\alpha_2 = 4\%$. The other random variables can be combined into a dispersion of $\alpha_2 = 9\%$.

$$\sigma^2 = 0.06^2 + 0.04^2 + 0.09^2 = 0.115^2$$

The probability of failure to be allowed in the calculations, taking into account the effect of « long struts », is $\varepsilon = 0.5\ 10\text{-}^6$, hence, $\eta = 4.89$

$$e^{\eta\sigma} = e^{4.89 \times 0.115} = e^{0.562} = 1.754$$

This coefficient applies to stresses which have already been increased by 10%. Thus the stresses must be increased by $1.1 \times 1.754 = 1.93$ or the limit of elasticity must be divided by 1.93 in order to compare it with service strain calculated for the standard train without increase :

$$\text{strain in service} \leqslant \frac{26}{1.93} = 13.5 \text{ kg/mm}^2$$

b) *For longitudinal bracing*, the breaking strain is that which can be repeated without any indefinitely increasing deformations resulting, say, 32 kg/mm^2 with a root mean square deviation $\alpha_1 = 6\%$.

Because of the dynamic effects, the normal live-load already increased by 10% is practically 1.265 times the total load + normal live-load : root mean square deviation $\alpha_2 = 5\%$.

For other random variables $\alpha_3 = 0.10$

$$\sigma^2 = 0.06^2 + 0.05^2 + 0.10^2 = 0.129^2;$$

The value to take for η is 4.75 (not very long struts, probability equivalent to $\varepsilon = 10\text{-}^6$), hence

$$e^{\eta\sigma} = e^{0,613} = 1.846$$

is the coefficient to apply to stresses increased by 26.5%. Thus, they are increased by $1.265 \times 1.846 = 2.34$. For live-loads of the standard train which have not been increased one must have :

$$\text{strain in service} \leqslant \frac{32}{2.34}$$

$$= 13.7 \text{ kg/mm}^2$$

The second example is of a road bridge in reinforced concrete of medium quality with plenty of steel rods. The breaking failure is the concrete's breaking strain, with a mean logarithmic deviation $\alpha_1 = 0.24$. It is now known that one must compare this, not with the bending strain calculated according to Navier's hypothesis, but with a strain reduced by 10% because of the effects of plasticity.

In the case of the live-load, it is all very well to admit that the normal traffic load will be reached half the time, but there is a possibility of over-looking the fact that an increase by 50% is not highly improbable in the distant future. Supposing that this difference corresponds in the logarithmic scale to three root mean square deviations, then $\alpha_2 = 0.135$ which can be reduced to $\alpha_2 = 0.12$ in order to take account of the smaller dispersion of the dead-load.

Lastly, the other random variables are amenable to a α_3 considerably higher than metal : let $\alpha_3 = 0.15$.

(long pieces, probability corresponding to $\varepsilon = 0.5 \quad 10\text{-}^6$)

With $\eta = 4.98$, then :

$$\sigma^2 = 0.24^2 + 0.12^2 + 0.13^2 = 0.294^2$$

and

$$e^{\eta\sigma} = e1.457 = 4.29$$

The result is the condition for safety under service strains (in terms of Navier)

$$\leqslant \frac{\text{breaking strength}}{0.9 \times 4.29} = 0.26 \text{ of the breaking strength.}$$

The breaking strength of hardened concrete is naturally intended.

It must be repeated that in all the calculations in the preceding applications, the numerical values employed still lack precision. Some of them are derived from statistical reports of a more or less advanced nature, others are estimates based partly on « hunch ». If the results deviate little from the usual rules, it should not be thought that the wish for such agreement affected the choice of α_1, α_2, α_3, adopted in the slightest.

As, therefore, a greater documentation should become available in the future and as it is likely that the numerical values corresponding to the truth will be reduced as knowledge progresses, it is to be expected that smaller and smaller coefficients will result.

Statistical analysis of tests of material, in particular, will expose the superiority, with regard to the tightening of the dispersion, of certain manufacturing methods leading to a revision of the safety coeffi-

cients which will procure important economic savings.

In this field, the centralisation of the dispersed literature which is available would be highly beneficial.

Factors affecting dispersion.

In conclusion, a brief indication will be given of the manner in which the theory of probability can be applied to structures, such as prestressed concrete, having a breaking point determined by the value of a function of the random variables which is not a simple ratio as has been considered until now.

First of all, normal standardized variates must be substituted for these variables. As the distribution function of a random variable X is assumed to be known, this can be done sufficiently well by use of a special graph paper, called Normal probability paper. The ordinates of this graph paper are equivalent to the function x which is introduced into the formula of the standardized Normal distribution (LAPLACE-GAUSS law) and they are marked off according to the corresponding values of the function F of the distribution, i.e. :

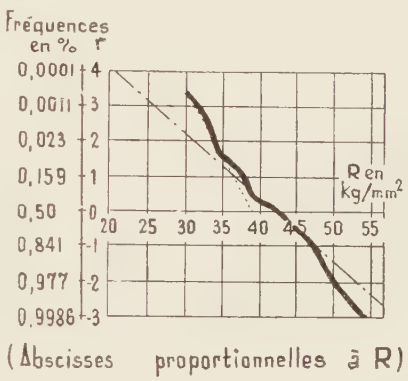
$$F = \int e^{-\frac{x^2}{2}} \frac{dx}{\sqrt{2\,\pi}}$$

Along the abscissa are marked the values of X corresponding to the integral probabilities assumed to be known (fig. 4.)

The curve described would be straight one if X followed the Normal distribution. It would be a logarithmic curve if X followed a logarithmic-normal distribution. In any case, it determines a change of variable x (X).

The dispersions of all variables X_1, X_2, X_3, ... X_i are thus all reduced to the same scale.

In probability terms, the limits occupied by a quarter, tenth, and a hundredth of the probabilities are called the quartile, decile and centile respectively. The last decile, the last centile, the last « millile »



(Abscissae proportional to R)

Results of tests on 10 000 test-pieces

Fig. 4.

begin at the values of 1.28, 2.32, and 3.1 of the Normal standardized deviates x_i. The number x_i, therefore, describes the position of X_i in the distribution, no matter what it is.

Attention will now be given to the equation :

$$G\ (X_1,\ X_2 \ldots . X_i \ldots .) = 0$$

which describes the condition of failure and to the partial differentials φ of G with respect of x :

$$\varphi_i = \frac{\delta G}{\delta x_i} = \frac{\delta G}{\delta X_i} \cdot \frac{dX_i}{dx_i}$$

The quantities φ determine, in an approximate manner, the effects that the dispersions of the various random variables X have on the possibility of failure.

Consideration of these factors causing dispersion first of all raises a qualitative point. It enables those random elements

to be discerned which, in comparison with others, are unimportant and can therefore be ignored. A random element such as, for example, the tension in the wires of prestressed concrete is rather dispersed. The last factor, written above, is in this case not insignificant but the corresponding strain is insignificant in relation to that causing the failure, which signifies that the last factor but one is very small, i.e. it has little influence on the dispersion. On the other hand, a random element which has a small dispersion, e.g. the eccentricity of wires in prestressed concrete, can have a not insignificant effect on dispersion because this eccentricity has a serious effect on the compression of the concrete.

Quantitatively, the factors affecting dispersion enable one to calculate fairly accurately the most probable conditions of failure, if this has a probability ε, by means of the equation :

$$\frac{x_1}{\varphi_1} = \frac{x_2}{\varphi_2} = \ldots \frac{x_i}{\varphi_i} \ldots = \frac{\eta_i}{\sqrt{\Sigma\, \varphi^2}}$$

In this formula, the dispersion factors have the same effect as the mean logarithmic deviations mentioned previously and all that was stated about the manner in which these parameters combine together is also still applicable.

It can be seen that if failure is possible, the most active factors are also those which must be found in the most abnormal situation, whereas the factors without noticeable influence can be considered as normal ones. In a vocal chorus, the force and character of a work are shown by the soloists far more than by the murmur of any member of the chorus.

To the multiple equation, must be added the condition of failure $G = O$ in order to solve the problem. The dispersion factors to be taken into account must, in consequence, correspond to the circumstances verging on failure. It is necessary, therefore, by means of a preliminary examination, *to determine the values of random variables which make failure particularly probable*, and it is in their direction that one must then examine the dispersion factors in order to obtain a better approximation.

By successive approximation, it is thus possible to determine sets of values for the different parameters studied which correspond to the desired degree of safety. These parameters are those which will be used in the individual stability calculations : dimension of sections, percentage of reinforcement, eccentricities, strengths, load and admissible live-loads, etc. The sets of values of different parameters can be grouped into one relationship where these parameters appear, for each type of structure. Even in the most complicated case, it is possible to condense the parameters into two or three terms only. Series of graphs or ready reckoners can be established, therefore, which enable the structural arrangements to be adapted to the stresses.

The employment of safety formulae differs from present practice : it will nevertheless not be slow in being propagated. It is proposed to introduce into the regulation methods of calculating no longer one safety coefficient alone, but different raising factors for loads and live-loads. To establish these new rules, one must be guided by something else than inspiration and probability theory provides exactly the means.

For example, let us return to the case of road bridges in reinforced concrete, and distinguish the *dispersion value* of the

basic weight, denoted by P, and that of the live-loads, called S. The first always being weak in relation to the second, the normal standardized variate associated with P is small and as the dispersion of P is equally little spread in relative terms, P is extremely close to its normal value when failure occurs.

For both types of load, there is the dispersion of the strength values, measured by $\alpha_1 = 0.24$ and the various random elements covered by $\alpha_3 = 0.15$. The quadratic sum of the logarithmic mean deviations is given by :

$$0.24^2 + 0.15^2 = 0.0801$$

In addition, one must take into account, in the case of the live-loads, the dispersion defined by $\alpha_2 = 0.135$, hence,

$$\alpha_1^2 + \alpha_2^2 + \alpha_3^2 = 0.3135^2$$

A simple calculation shows that the condition of failure, having a probability of 1 in 100 000, taking into account the effect of long pieces, are obtained by maintaining P, multiplying S by

$$\exp\left(4.89 \frac{0.135^2}{0.3135}\right) = 1.327$$

and in multiplying the normal strength (i.e. the resistance to compression divided by 0.9) by :

$$\exp\left(4.89 \frac{0.0801}{0.3135}\right) = 0.287 = 0.9 \cdot 0.318.$$

Consequently, the safety formula is as follows :

« The bending strain, calculated as a result of maintaining the basic load P at its normal value and increasing the normal live-load by 33%, must not exceed the 32 hundredths of the normal strength, after hardening. »

Conclusions.

In conclusion, if the mathematical apparatus which must necessarily accompany all statistical theory surprises generally those people not familiar with these kinds of calculations, the results are, on the contrary, easy to use.

The remarks made on this subject, rather laborious at the beginning, undoubtedly lead to a correct appreciation of things. They enable one to distinguish clearly, among the divergencies which nature presents us with and which we begin by neglecting, those which are most likely to render false the simplified representation of phenomena that we indulge in, and those which are inoffensive.

Probability calculations, even if the data used are imprecise, indicate the order of magnitude of the margin in reserve against the total of uncertainties from which we must protect ourselves. They also show which ones must be given most attention to reduce their effects.

As from now, this kind of consideration and analysis should be profitable to structural science. To prepare future improvements, it would be desirable for engineers to interest themselves in the following subjects :

— calculation of ultimate strength, or more precisely, failure,
— statistical analysis of characteristics of materials,
— variations of these characteristics along a beam,
— statistical analysis of actual strains related to estimated strains,
— statistical analysis of exceptional wind forces.

[656 .222 .5 (492)]

Bases on which the timetables of the Netherlands Railways are prepared,

by W. J. De Graaff.

(*De Ingenieur*, No. 1, 4th January 1957.)

Summary.

To keep the timetables in line with the requirements, it is desirable to analyse the characteristic features of the passenger traffic. All heavy concentrations show themselves to be, in different ways and to varying degrees, economic centres for attracting traffic and are the basis of it, in proportion to their extent and importance, the traffic invariably being greatest in density and volume in the immediate vicinity and decreasing rapidly as the distance increases. Short journeys predominate, 85.3 % of the Netherlands Railways traffic is of regional character and only 14.6 % is inter-regional or long distance.

It is noted that inter-regional traffic is largely concentrated over the main traffic arteries connecting the western provinces, which are the most developed in commerce and industry, with the centres of other provinces.

The timetable of the Netherlands Railways is based on the three principles of regularity, frequency and most favourable connections : it serves regional and inter-regional traffic by a single system of trains, mostly semi-direct, covering all lines according to a regular timetable. The normal service over practically all lines is based on hourly intervals so that in each hour there are the same facilities for connections, with the result that each hour of the day any station can be reached from any other station.

The three main systems which form the framework of the system are describes each with its related system of secondary lines. The special requirements of regional traffic at peak periods are a pointer to future development.

The advantages and disadvantages of the system are also mentioned.

The method of compiling the Netherlands Railways Timetable rests on principles which are really suitable for it and differ greatly from those seen in this sphere in other countries.

Taking as fundamental principles; regularity, frequency and easy connections, there has been built up during the past twenty-five years a system which allows a passenger to arrive in any hour, at each station in the country from any other station whatsoever, travelling in each case for the same length of time and with identical arrival and departure times.

Why is this so? What are the guiding factors? How has this diagram been formulated, with its multiple connections?

I. Characteristics of passenger traffic.

If it is to fulfil its purpose and provide the anticipated commercial results, the railway timetable must satisfy the needs of the public who wish to travel. The starting point is therefore to forecast the demands of the public. What is learned by those who compile the timetable, when they are informed by the passenger of his needs and preferences?

A train which departs and arrives at times most suitable to the passenger, which is fast and preferably does not stop at stations where the passenger is not affected, and which in addition ensures the necessary transit without changing : such demands are generally made by the public on the railway timetable. The Netherlands Railways carry daily about 500 000 passengers and for this purpose run about 2 500 trains per day. It is obvious that individual requirements will conflict at many points. We must then make every effort to find a general average as a guiding line on which to base the timetable.

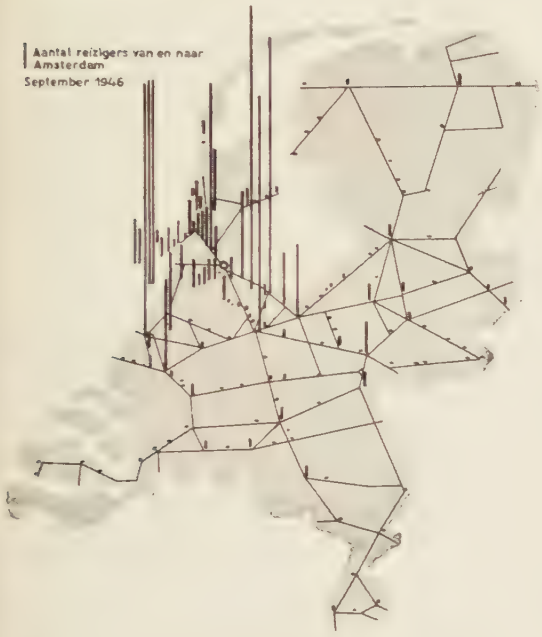


Fig. 1. — Geographical distribution of railway passenger traffic to and from Amsterdam. The height of the uprights shows the number of passengers carried to and from the point in question.

N. B. — Aantal reizigers van en naar Amsterdam, September 1946 = Number of passengers to and from Amsterdam, September 1946.

Regional characteristics.

If the analyse passenger traffic as departure and destination points at any station in Holland in regard to geographical dispersion as well as number of journeys and if we summarise the results in diagrammatic form (see fig. 1, as an example, for Amsterdam) we are immediately conscious of the regional concentration of traffic. Business and social journeys are always most numerous and most intensive in the immediate neighbourhood and decrease rapidly in number as the distances increase. Thus, traffic by rail between Amsterdam (860 000 inhabitants) and Weesp (9 000 inhabitants), 13 km apart, is approximately of the same intensity as between Amsterdam and Rotterdam, which has 700 000 inhabitants but is 90 km away.

The same picture is shown whatever town is selected (see fig. 2 Maastricht); traffic always appears to be concentrated predominantly in the immediate neighbourhoud. The statistical pictures obtained always show that each town is an economic and social centre of its kind and to its own degree, from which traffic originates and to which it flows according to its size and importance. Regions which are highly developed commercially and industrially provide traffic not only proportionately denser but also for conveyance over longer distances. From the traffic point of view, commercial and industrial centres of activity, administrative centres and so on, are generally the most important. This means that the western centres of the country are shown by the figures to have traffic of comparatively great importance.

The number of population, structure of professional activity and distance are the determining factors for the scope of traffic.

Fig. 2. — Passenger traffic with Maastricht.

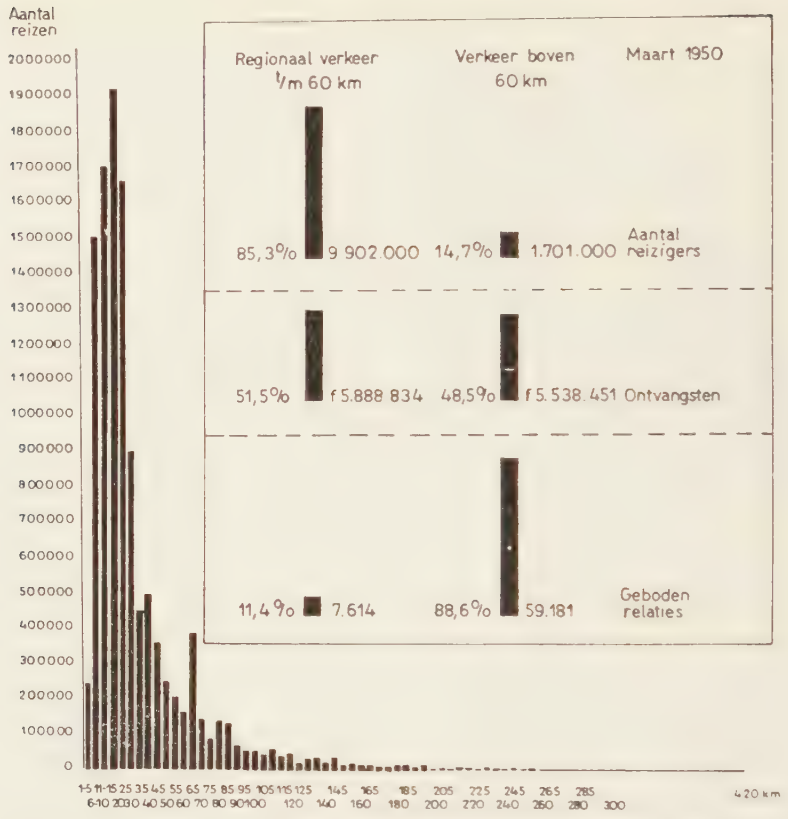


Fig. 3. — Distances of passenger journeys in km groups of ordinary and return journey traffic, reduced to single journeys. Total number : 11 603 000. March 1950.

N. B. — Aantal reizen = number of journeys. - Regionaal verkeer = regional traffic. Verkeer boven 60 km = journey over 60 km. Aantal reizigers = number of passengers. - Ontvangsten = recepts. Geboden relaties = point to point services offered

The consequence of this regional concentration of traffic, for the traffic conveyed by the N.S. is that there is a great predominance of short distance passengers. Figure 3 shows the relationship between the number of passengers carried and the journeys made, which clearly shows the predominance of journeys of 10 to 25 km with the highest numbers in the 15-20 km. range. Expressed in percentages of the total number of journeys, we see that :

45.3 % of journeys do not exceed 21 km;
59.8 % of journeys do not exceed 26 km;
67.7 % of journeys do not exceed 31 km;
75.9 % of journeys do not exceed 41 km;
85.3 % of journeys do not exceed 61 km.

The function of mass carriers — which is what the railways are by their technique — is thus fulfilled by the N.S. insofar as regional traffic is concerned.

Facilities over the whole country.

Limiting the conception of regional traffic to a distance not in excess of 60 km, 85.3 % of the N.S. traffic is of regional character; only 14.7 % of the traffic relates to journeys of more than 60 km and can be regarded as inter-city.

The relatively small number of inter-city journeys (14.7 % of the total) is, however, of great importance from a financial point

of view, it provides about 50 % of the passenger receipts. The task of the regional carrier, which implies the use of expensive equipment designed for mass transport can be accomplished, from the financial point of view only with the aid of receipts from long distance traffic.

In the third case, it is important to note that the number of small distance services offered by the N.S. is relatively small and is only about 11.4 % of the total services. Long distance travellers, on the other hand, have not less 59 181 point to point journeys (88.6 %) although only sporadic use may be made of some of them (for example, Workum-Spekholzerheide). Although it is undoubtedly of a more sparse and scattered nature than short-journey traffic, long distance traffic has nevertheless definite concentrations over certain important railway routes. A more detailed study shows that there is a concentration on routes which connect the west with the most important centres of the other provinces. Examining the points of origin and destination of this traffic it is seen that 75 % of travellers in Holland itself leave the large towns with direct connections between them and only 25 % the lateral lines. The destinations are, for 85 %, the main centres of other provinces and for only 15 % secondary lines or small intermediate stations.

The traffic between secondary lines (or small intermediate stations) is only 3 to 5 % of that over the main routes already mentioned.

Object of the timetable.

Apart from the feature, which will be discussed in detail later, of the marked concentration of traffic over certain hours (or days) for both short and long journey traffic, which the timetable must cater for by greater train density, we can summarise as follows the objectives to be satisfied by the timetable, bearing in mind the features mentioned above :

1) assist the demands of the region for short-distance mass traffic;

2) provide the means of interprovincial transit by through services between the centres of Holland and other provinces of the country;

3) for least connections suitable for the light and widespread long-distance traffic between the different parts of the country.

II. **Timetable compiled by the Netherlands Railways.**

The system of timetables compiled by the Netherlands Railways over the past twenty-five years to meet the detailed requirements mentioned above are based on three principles :

— regularity;
— great frequency;
— assured connections.

Regularity of service.

The essential characteristic of a regular service is the even interval in the succession of trains, the rhythm and cadence. It is, in fact, better to think of a rhythmic service. It is fundamental to consider, in this respect, equal speeds as well as equal times of arrival and departure throughout the day.

Frequency.

The rhythm of the service cannot be the same throughout — the intervals are related to the density of the traffic. The datum of the N.S. in this respect is an hourly service, with 30 or 15 min densities on routes with heavy traffic, or in some cases 20 minutes. At peak periods, the scheme is padded to meet the demands, but on certain feeder lines the plan is reduced to two hours or some trains are withdrawn at slack periods.

The regular service and frequency have been developed over the years because of the special geographical position and resultant traffic structure. The concentration of the population in the « ring of towns called Holland » demands high frequency which leads readily to regularity under the influence of the need for circulating rolling

stock, the possibilities offered by this must also be borne in mind, especially as it relates to short distances. The regular service, which is based on the Amsterdam-Rotterdam-Utrecht triangle has been progressively extended throughout the country simultaneously with the introduction of electric or Diesel traction.

each hour from any station for any other station in the country and above this to leave at about the same time within the hour. This tendency has given its own aspect to what we call the nodal system; fast trains running on the main routes in a regular service with a set rhythm, connect at terminal stations and interchange sta-

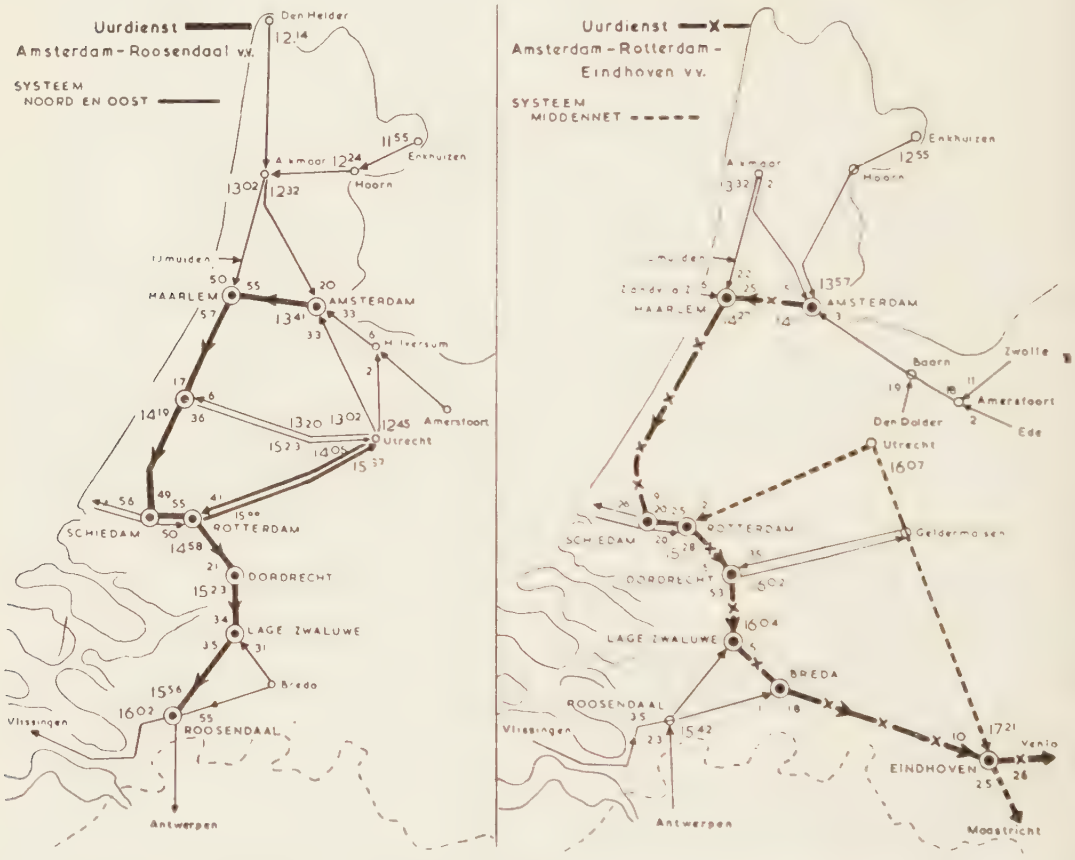


Fig. 4. — Basic diagram of the « Old Line », two services, giving half-hour services, each with the same connections repeated each hour.

Connections : each hour, departing from any station for a journey to any other station.

A special effort has been made to establish a network of reciprocal connections such that a passenger may depart

tions with services to and from small lines. The principle of feeder lines is applied systematically and by concentrating secondary services there arise definite interchange at nodal points on fast train routes where, with the same rhythmic frequency as fast

trains, there are other trains which arrive and depart over secondary routes.

It may be mentioned here that the type of train on the N.S. known as « rapide » is primarily of the semi-direct type according to ideas in other countries. All our inter-provincial trains stop at some intermediate stations of which more than one has no importance such as would justify a long distance train stopping there. Long distance journeys outside a perimeter bounded by Zwolle, Deventer, Den Bosch, Dordrecht, are not sufficient in number to warrant an hourly interval service with sufficient occupation of available seats, without the addition of local line traffic. On these lines it is not possible to justify a one-hour frequency as well as a stopping service for intermediate stations. Our fast inter provincial trains must, therefore, as a general rule fulfil both functions : long-distance journeys and local line traffic; these are semi-direct trains.

Structure of the timetable : three basis diagrams.

The geographical situation is in essence the determining factor on the structure of the timetable. The Dutch « ring of towns » (Randstad Holland) has three focus points : Amsterdam, The Hague, Rotterdam.

Each of these has its own connections with important localities of the South, North and East. Only the direction of traffic towards the South-West (towards Belgium and France) is similar for the three points and can, because of this, be met by the same train service.

Towards the North, East and South-East, the situation is quite different and, because of the geographical situation, three distinct traffic streams flow to and from Amsterdam, The Hague and Rotterdam. These traffic streams for the Arnhem-Nimegue and Eindhoven-Maastricht directions intersect or are tangential to each other at Utrecht and those for Groningue-Leeuwaarden do the same at Amersfoort.

In making the train service to suit the more important traffic streams to the main provincial centres, it is quite naturally found that the starting points for suitable diagrams for the three interwoven basic diagrams are Utrecht and Amersfoort, these being clearly indicated by their geographical location to become basic stations for hourly connections between identical groups of trains.

The N.S. timetable is thus based on the three diagrams described below :

Old line (1) (fig. 4).

1. In the first place, the basic diagram of the « old line » is made up of two regular interval services which cover :

Amsterdam-Rotterdam-Roosendaal (later extended to Flessingue), and Amsterdam-Rotterdam-Eindhoven-Venlo.

Together, the two services provide a service at half-hourly intervals over the section Amsterdam-Lage Zwaluwe.

On these two services a suitable system has been built of connecting trains for passengers to and from the secondary lines. Certains important through connections are available because of the half-hourly service with the two basic services (region of Gooi, Zaan, Kesnnemerland and Vlaardingen) : other directions, less important, can be serviced by the normal timetable (Betuwe line, from Leiden-Woerden and from Enkhuizen). At Rotterdam, the old line acts as a feeder for North-South traffic and inversely, this works for traffic on the old line for the Dordrecht direction.

At Lage Zwaluwe, the two systems of the old line act as reciprocal feeders to each other (triangular operation). The illustrations show that each hour throughout the day there are connections at the same times which allows each hour the same facilities : for travel to all other stations on the system and by means of connections via Rotterdam to other systems and consequently the whole country.

(1) *N. B.* — The name « Old line » (Oude Lijn) refers to the Amsterdam-Rotterdam-Dordrecht line.

Bridge-openings at Rotterdam and Dordrecht, required in principle for twenty minutes every two hours for shipping, compel inward and outward trains to pass on the bridges or in the near vicinity; only in this way is it possible to provide the required interval for opening the bridges. Thus, the establishment of the *Central system* (fig. 5).

2. Utrecht is the point where the streams of traffic between Amsterdam and Maastricht, and Arnhem-Nimegue and the similar flows between The Hague and Rotterdam converge or cross. Trains on these systems arrive at Utrecht each hour at

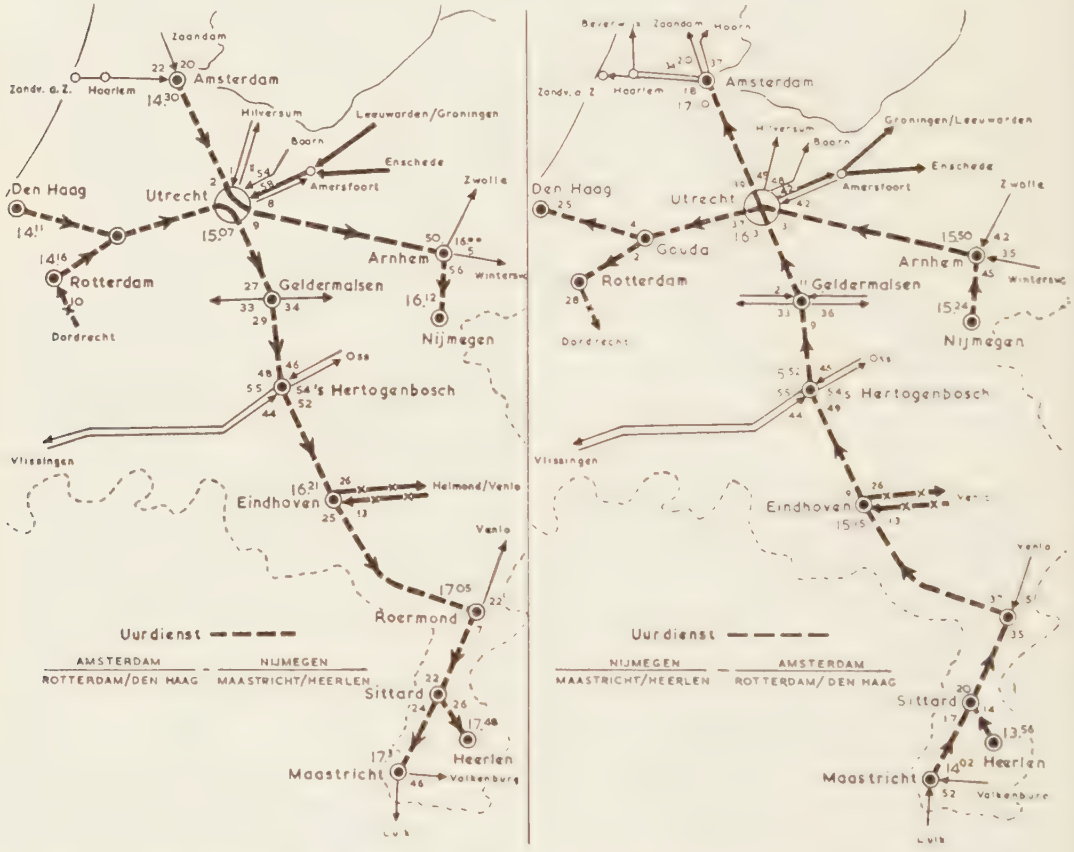


Fig. 5 — Basic diagram of the central system; two scheduled services joining at Utrecht with feeder services for connections, repeated regularly every hour.

reciprocal point-to-point services in both directions has an effect throughout the entire system because of the principle of interconnection. These services are a determining factor in the compilation of the timetable.

the same time, each on its own side of the same platform, to give the passengers each change of train. In order to give each service the same number of changes there is a system of cyclic permutation every hour by means of which the two streams

of traffic (Amsterdam towards Arnhem and The Hague-Rotterdam towards Maastricht) converge at odd hours and cross at even hours (Amsterdam to Maastricht and The Hague-Rotterdam to Arnhem).

The branches to The Hague and Rotterdam combine or separate at Gouda. Figure 5 shows how the « old line » fulfils at Rotterdam the function of feeder and that at Utrecht there are very good connections with the North-East fast trains and the central system. Traffic between Brabant and Limburg on one hand and between the North and the East on the other hand are thus well provided with a very good connection every hour at Utrecht.

The ebb and flow system on secondary lines is again realised at various interchange stations : Amsterdam, Utrecht, particularly Geldermalsen, Den Bosch, Eindhoven, Maastricht and Arnhem : this is shown in figure 5 : each hour at the same time with all parts of the country.

Connections with the North and East (fig. 6).

3. A situation similar to that at Utrecht for the central system, also exists at Amersfoort for traffic streams for the North and East : traffic streams from Amsterdam converge on or cross those from Rotterdam, The Hague and Utrecht and also that coming from the South which is itself carried by the central system. Here also a cyclic permutation of the service has been arranged.

Trains on the « old line » act at Rotterdam as ebb and flow lines.

Combination of branches from Rotterdam and The Hague is achieved at Utrecht. The connections for joining or leaving trains at Amsterdam, Amersfoort, and again in particular at Utrecht, Zwolle, Groningue and Leeuwarden, as well as Apeldoorn and Deventer, also provide the opportunity of leaving any Netherlands station any hour for any other station, from Roodeschool or Flushing.

Complementary regional schemes (fig. 7 and 8).

In the same way as on the trunk lines, complementary connections have developed on the regularity, frequency and case of inter-change. Let us take for example the system in the province of Noord Holland.

An hourly service Amsterdam-Haarlem-Alkmaar (i.e. through Kennemerland) together with a similar hourly service Amsterdam-Alkmaar by Zaan, forms a regular half-hourly service on the section Uitgeest-Alkmaar. Complementary services every hour between Amsterdam-Uitgeest by Kennemerland and by Zaan not only provide a service every half-hour between Uitgeest-Alkmaar, but, also half-hourly connections at Uitgeest, so that, finally, Alkmaar is connected to Amsterdam as well as Haarlem by a service every half-hour; alternatively, it is necessary to change at Uitgeest or to continue on the same train.

Outward and return journeys are so arranged, in relation to each other, that at Uitgeest there are branch connections from Zaan for Kennemerland and vice-versa; futhermore, at Amsterdam there are connections from Haarlem for and from Zaan. Trains in the two directions cross at Velsen-Ijmuiden Oost, where a connection is available every half-hour to and from Ijmuiden.

In addition to the nodal point of this regional diagram at Uitgeest, the stations of Alkmaar, Hoorn and Velsen-Ijmuiden have regular assured connections whilst the whole regional system is integrated with the system established for the whole country by connections at Amsterdam with the central system as well as the North and South and at Haarlem where, every half-hour, there are connections through trains of the « old line » with Roosendaal and Eindhoven.

If we also consider that in the regional system of Noord-Holland the circulation of trains must be regulated so that trains in the two directions must cross on or very near the bridge by Velsen and Hembrug, to allow for their opening twice every hour for navigational purposes, it

will be appreciated that even we on the N.S. are astonished at the harmony which has been achieved.

In the same way as Noord-Holland, Limburg (fig. 8), Twente, the Ijssel region, Groningue, etc., all have regional timetable systems of their own, aligned with the national system which is thus all the more rigid.

It is quite obvious that in such a wide-

Fig. 6. — Basic diagram of services to the north and east : two hourly services into Amersfoort with their connections on arrival and departure.

spread system of connections the consequences of a local modification would have wide repercussions. This is the case with the reconstruction of Hem tunnel, which increased by four minutes the journey time from Amsterdam to Zaandam. If it is desired to maintain the Noord-Holland regional system, with connections at Uitgeest, Alkmaar, Hoorn, Velsen-Ijmuiden and Haarlem, trains for Zaandam will have to leave Amsterdam four minutes earlier and arrive from Zaandam four minutes later. This means that if connections are to be retained at Amsterdam with fast trains for Twente and Friseland-Groningue, these will have to be retimed. This, however, is not possible because of track and station occupation and would involve the stoppage of stock for Enschede and Leeuwarden. This retiming would cost, in the absence of alterations to station equipment, the use of at least two more trains.

If we look for another solution, similar problems arise, for example a change in the two directions of travel on the « old line », this would have the remarkable consequence that the elimination of the Hem bridge would cause a reduction in the time for opening the Meuse bridges at Rotterdam and Dordrecht.

Some considerations of the system and its consequences.

The system applied throughout of *connections* locates and fixes rigidly, one within the other, the main countrywide system and the regional systems, by which the rhythm of traffic at a one-hour frequency is felt in the most remote coverns : each hour provides a renewed opportunity of reaching each station from any other station.

The connections however have the disadvantage as well as the advantage, that they are a very complicated network with a great amount of interdependence. Without there being any expressed demand a complete ring of connections has been established in the Amsterdam-Rotterdam-Utrecht - Hilversum - Amsterdam quadrilateral, with connection times of 5, 8, 4 and 8 minutes (fig. 9). This ring embraces 3 hours and continues throughout the day

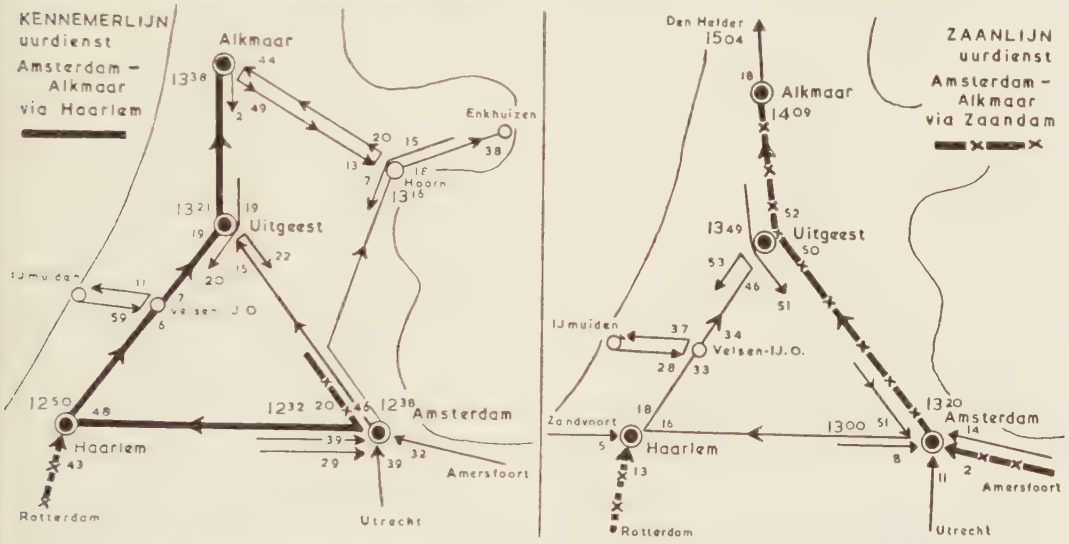


Fig. 7. — Noord-Holland regional system : two hourly services combined to give half-hour service with a complicated group of connections.

even though it may not in spite of its scope, be fully used by any passenger.

Unplanned, but inevitable, complete circuits and cross links have occurred at various points which lead to rigidity and interdependence of train movements. With regard to operation, there is undoubtedly a certain vulnerability in the system because of the cumulative effect of delay.

frequent service and ensure the connections being made.

A disadvantage of the system is that the train timetables cannot be adapted to the times of works opening and closing, nor to changing situations. The very great frequency of trains reduces this defect which moreover, one can only alleviate by interposing extra trains. A second disad-

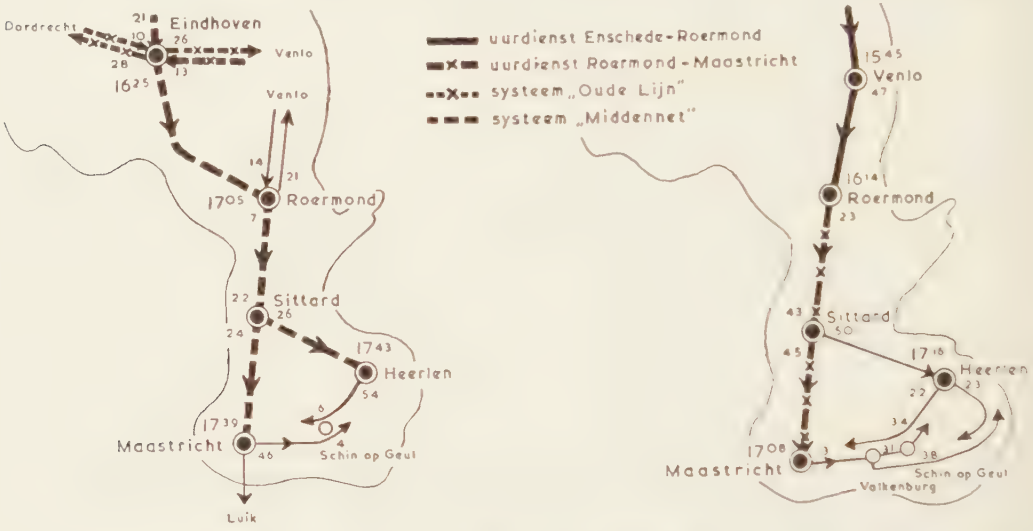


Fig. 8. — Limburg regional system : two hourly services combined, those of the central system and those of the local service Maastricht-Roermond connecting with the Roermond-Nimegue / Enschede with their connections for arrival and departure.

Regularity is considered by the public as a definite advantage, and for service purposes too; it is also favoured because it allows, in conjunction with the greater frequency of trains, intensive rostering which is good for rolling stock and train crews. The regular service has a corollary that the same trains or types of trains pass or cross always at the same stations; shunting and train movements are thus as uniform as possible from hour to hour. Naturally, track, station equipment and signalling are adapted to the timetable structure so as to give a service procedure which is quick, uniform, and simple, which is very important with a regular and

vantage is that the length of stopping times at stations cannot very well be adapted to changing requirements. At peak hours, and particularly with station duties extra work which is not spread over the day but requires longer halts (mail despatch, parcels traffic, newspapers) the interval service is most vulnerable. It is not readily adaptable for attaching and if necessary detaching carriages : shunting time must be spread over the whole day or it cannot be worked.

The system is thus admittedly less flexible, not adaptable without great difficulty to local requirements or very close conformity to traffic demands. It aims

to be the greatest common divisor of traffic demands but cannot be more. It is suited to general demands but must ignore certain details.

The renunciation of certain transport work is inherent in the system and has been deliberately undertaken on a wide scale at the introduction of the system. The construction of the present timetable which is a process which has taken a few years to realise has been concurrent with the entry in competition of the motor bus,

Fig. 9. — Vulnerable interdependence of systems : occasional connections of closed circuits and cross links.

which has drawn off a lot of traffic from rail to road and caused the closing of many small stations and secondary lines.

On numerous lines, particularly where the traffic originating warranted an omnibus service, there remains only one type of train, the semi-direct, and consequently there is no mixed service of fast and slow trains. The system and, at the same time, the train service has been drastically purged by the closing of intermediate stations In this way — particularly by limiting the number of intermediate stations — we are releaved of the need to allow stopping trains to be passed by fast trains other than at nodal points, but never on open track. The stopping train thus serves at the start for carrying passengers from the preceding fast train and at the same time acts as a feeder at its destination for the following fast train.

III. **Needs of peak hours and extra trains** (fig. 10 and 11).

With the diagrams drawn up as described, however, the needs of the traffic have not been fully provided for. The diagrams give each, for itself and relative to each other, the *basic arrangements;* the frame on which each is fashioned and built up. Following the demands, trains are added on specified lines and at certain hours (or on certain days); shuttle service trains, relief train preceding or following regular trains, additional Saturday afternoon, Sunday evening or Monday morning trains, leave trains or international trains. Passenger traffic is subject to peaks and these occur not only in short distance journeys but also in interprovincial and even international traffic. The « Gooi » line, the « old » line and other sections of line also serving specially for transit traffic for interprovincial journeys such as Amersfoort-Zwolle, Amersfoort-Apeldoorn and Eindhoven-Roermond, are also subject to these fluctuations; throughout the country, over all lines at the same times.

During these peak periods the normal timetable is inadequate and extra trains have to be run. This gives a beneficial indication for the future : subsequent development of the timetable will not be in the way of closing up the framework. Interval service of one hour or half an hour are quite adequate outside peak periods. Whilst there may be special problems, these occur at peak periods. It is right, at this point, to examine requirements in detail and apply special measures in the form of faster additional trains, or trains with indirect routes. The needs for present peak traffic would quite certainly be

those which increased traffic would cause, in future, to run during the greater part of the day and the additional peak hour trains at present and in the near future will give way, in a subsequent stage to the development of a new framework of wider regular services, set up alongside semi-direct trains as at present and faster than them.

Analysis of requirements at peak periods is thus particularly important; the transport of two-way short journey passengers is thus relatively easy, but inter-provincial (long-distance traffic) is, on the contrary,

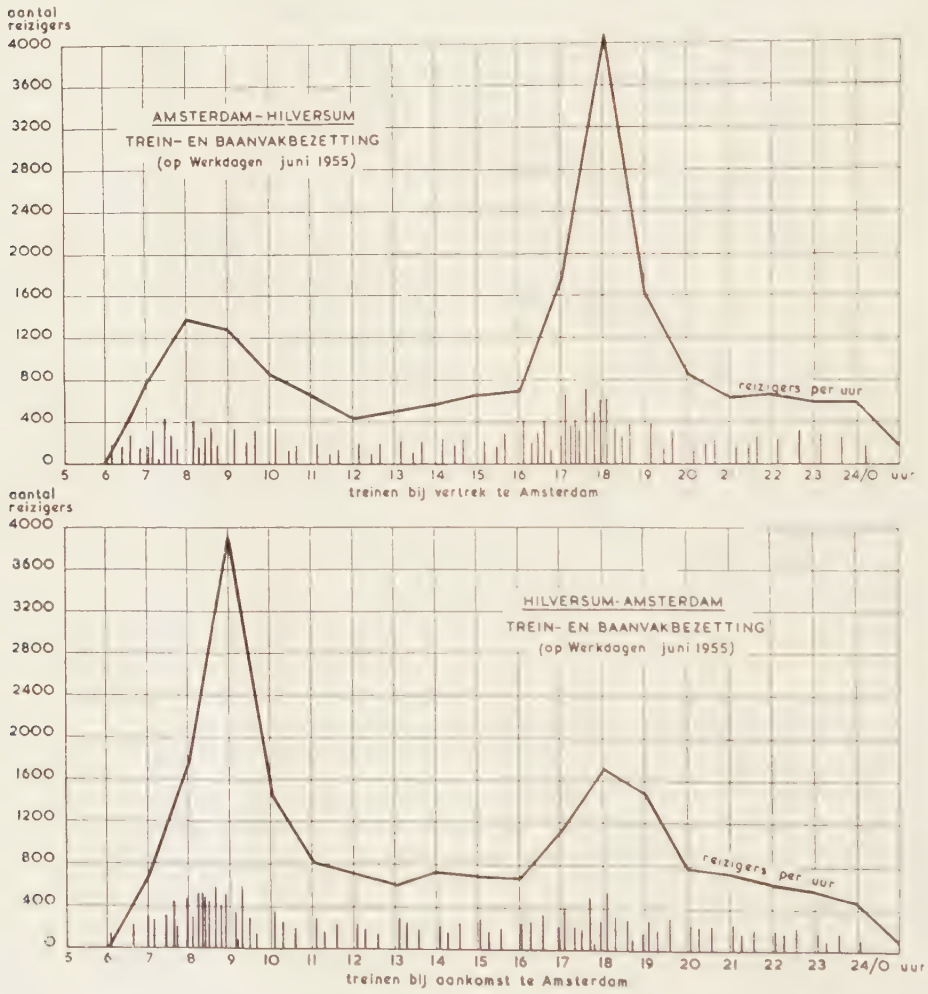


Fig. 10. — Peak traffic Amsterdam-Hilversum and vice-versa. The height of the uprights shows the occupation by various trains on departure and arrival at Amsterdam.

N. B. — Trein- en baanvakbezetting (op werkdagen, Juni 1955) = train and track occupation (weekdays, June 1955). — Treinen by vertrek te Amsterdam = trains departing from Amsterdam. — Treinen bij aankomst te Amsterdam = trains arriving at Amsterdam. — Reizigers per uur = passengers per hour.

very complicated and it is desirable to examine the needs of the traffic flow for each train.

Let us take for example the inter-provincial traffic between the province of Holland and Friesland and Groningue. Figure 11 shows the number of inter-provincial passengers travelling Northwards on ordinary working days with the various trains shown in the timetable. The requirements of the morning and afternoon peaks are clearly shown. This is, moreover, a

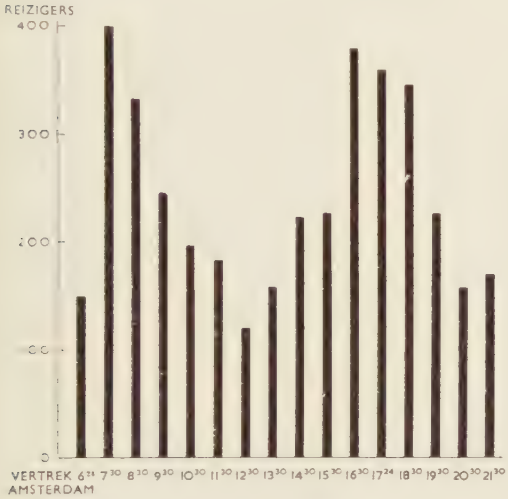


Fig. 11. — Fluctuation in number of interprovincial passengers (Holland-Zwolle and beyond) Interprovincial traffic is concentrated at particular hours.

reflection of all lines and all inter-provincial journeys : 40 to 50 % of inter-provincial passengers start their journey between 7 and 9 am. and 4 and 6 pm., i.e., twice a day in a group of two or three successive trains. Inter-provincial traffic is thus concentrated on certain hours of the day and, as regards departure and arrival times, calls for a service which is no less definite than that for short journey travellers. Thus there are special demands to be satisfied at particular times. A good forecast well in advance, therefore, will have to take account of this by inserting additional and faster trains : departures between 7 and 8 am. and returns between 4 and 5 pm.

On Saturdays, Sunday evenings, and Monday mornings the peak times are quite different, following very different demands which must be met by appropriate measures.

However, « there is many a slip twixt cup and lip ». It is obvious that it is primarily at peak hours that the limit of station and track capacity is reached : increases in the number of trains at these times are often impossible without major engineering works. The increase just mentioned in the number of trains does, in fact, demand considerable work at a number of stations. When these are carried out it will become possible to introduce each hour express trains which are, however, only justified at peak hours. This story repeats itself on a larger scale and under another form : the frequent semi-direct service as we know it now has not been able to develop amongst the old and slow stopping trains. The latter traffic has been diverted to the roads leaving the railway clear for the fast and frequent service we have now. However, even faster trains have, in their turn, a need for space which at the moment is refused them in the existing framework. Now it is necessary to carry out engineering work to obtain space so that the transfer should not take place.

IV. **Timetable technique.**

It remains to deal with the technique of making up the timetable and to show how, starting with running and stopping times, we can establish the desired result of reciprocal connections at a number of points.

The components of the timetable, that is the running and stopping times, are governed by the mechanical possibilities of the track, the equipment of the stations, and the types of traction and loads, as well as the signalling equipment. It is also necessary to add to this list the amount of rolling stock available and the absolute minimum time necessary at terminal points before returning.

In principle, the running of trains — the service which the railway industry provides and sells to the public — is determined by the equipment needed to produce it. It is, however, obvious that at a large number of secondary points, the services must be subordinate to the equipment available.

Type of traction.

Taking into account the speeds allowed on various sections and local speed restrictions, we can fix, by various calculations and test runs, the running times for different speeds and types of trains : electric multi-unit sets, locomotive - hauled trains, Diesel - electric trains and motor coach sets, etc.: for hauled trains, differing loads and composition (passengers and freight).

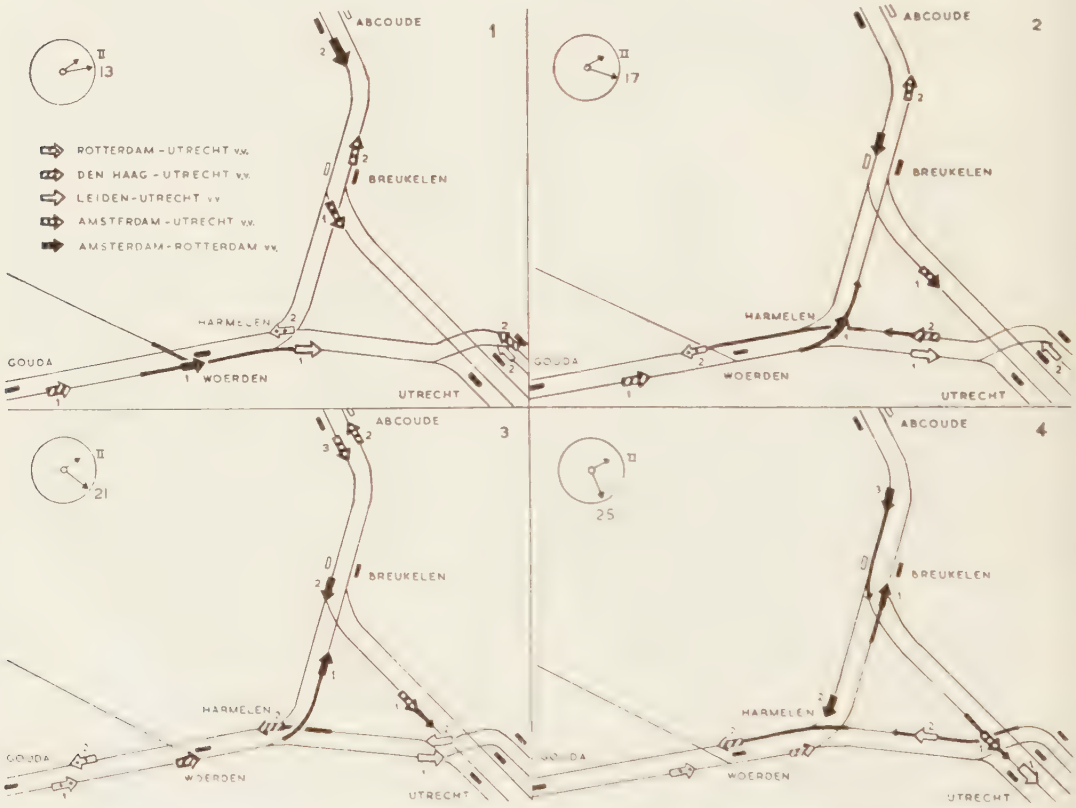


Fig. 12. — Interdependence of train movements. Succession at short intervals of concordant and crossing train movements in the triangle Harmelen-Breukelen-Utrecht.

The track.

The standard and condition of the track, such as gradients, curves, types of ballast, types and weights of rail, condition of bridges and other structures impose certain limits on permitted speed and those imposed differ with the type of rolling stock. These limits are fixed by regulations.

These running times constitute one of the factors on which the timetable is formulated : they are results taking into account operating/rolling stock and operating/track data.

Standing time and movement of stock.

With the running times, the standing times at stations and the times for movements of stock which have to be undertaken at stations form another important element. The times needed for boarding and alighting, connections, coupling and uncoupling, signal : no train must enter a block section, that is a section of track between two signals, before the preceding train has left that section.

The compiler of the timetable must know at how many minutes interval the movement of trains can proceed without reaching a stop signal.

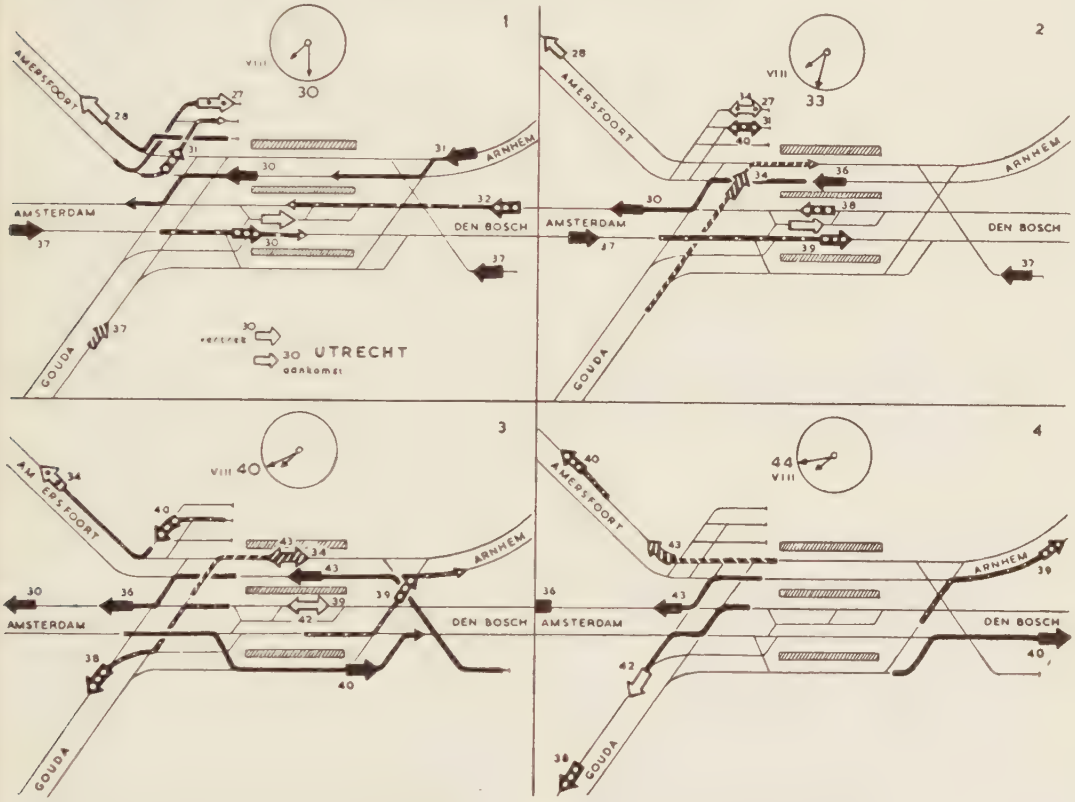


Fig. 13. — Arrival and departure movements at Utrecht. Crossing movements following at very short intervals.

locomotive movements, etc., must be calculated and shown.

Signalling.

A train is not alone on the line : in front and behind, care must be taken to have always sufficient space to ensure safety. Always, between two trains, there must be at least one signal which is a stopping

The situation at junctions is even more complicated : let us take for example the triangle of lines Utrecht-Harmelen-Breukelen and the operation of trains each hour between A + 13 and A + 25. These operations can be concordant, conflicting or independent. Concordant trains (for the same destination) must remain at a sufficient distance from each other : at

least one block section apart. Even in the case of conflicting trains, it is necessary to provide sufficient time between the movements of trains. Here, too, when a block section is temporarily occupied a second train cannot enter and the latter will meet a stop signal.

Figure 12 shows four positions arising successively between Woerden and Harmelen where a group of four trains operate at an interval of about 4-5 minutes; the train from Leiden towards Utrecht, followed by a Rotterdam-Amsterdam train, then the Hague-Utrecht train and finally Rotterdam-Utrecht. Simultaneously, a group of four trains are running in the reverse direction : Utrecht-Rotterdam, Utrecht-The Hague, Amsterdam-Rotterdam and Utrecht-Leiden.

It is necessary for the Rotterdam-Amsterdam train to leave the group near Harmelen across the path of the four trains in the reverse direction : four minutes after the passage of the end of the Utrecht-Rotterdam line, but also four minutes before the Utrecht-The Hague train; this movement splits exactly the timing of two successive trains (sketch 2 of fig. 12).

Sketch 4 shows how the Amsterdam-Rotterdam train takes its place in the succession of trains 4 minutes after the Utrecht-The Hague and four minutes before the Utrecht-Leiden train. To allow the operation of this movement, it was necessary in 1954 to double-track the section Harmelen-Breukelen. Sketch 4 of figure 12 also shows how the Rotterdam-Amsterdam train passes the Breukelen Junction 4 minutes before the Amsterdam-Utrecht train crosses the same junction in the opposite direction. The preceding Amsterdam-Utrecht train arrives at Utrecht as the preceding Utrecht-Leiden train clears the road.

The high frequency and bunching of a large number of trains with a small period of time in many connecting stations, which is inherent in the system chosen, gives rise to many problems relative to track and line occupation. It causes at many places conditions which allow small tolerance in train movement.

Stations.

It is clear that stations are one of the main concerns in the organisation of the service. Trains must be formed at stations, be loaded and unloaded, additional coaches must be coupled and uncoupled, locomotives changed and connections ensured. Trains must, therefore, be at the available platform at a suitable time; they must be able to arrive without obstruction and after an appropriate period (sometimes longer than is strictly necessary) be able to depart without hindering or being hindered by another train. Approaches to main stations are therefore, whether they are one or two tracked, the points where at certain times a large number of train movements must be carried out and these cause the most complicated timing problems; it is frequently necessary to make sacrifices in the form of loss of time or lose a connection which might be possible. All trains cannot enter simultaneously at the most suitable moment. This is the result of the reciprocal connection between the timetable and the equipment. Although the demands of the timetable determine the principal features of the equipment, conversely the availability of the equipment determines the details of the timetable.

The system based on a frequent service with connections to and from all directions, repeated every hour and carried out in a minimum of time causes at key stations such as Utrecht and other junction points a large number of train movements which are mutually conflicting (fig. 13).

The four successive situations shown in this figure how the station is completely filled, how the connections are made and how the station becomes clear again. A large number of conflicting train movements must be carried out with the shortest possible time interval.

An examination has been made of all possibilities for providing station facilities. Movement of trains is studied, in practice, to the minute, and maximum efficiency obtained from the stock of vehicles by

providing very short intervals at terminal points before re-use.

A small modification to a single train in the timetable, which is a minutely detailed compilation, very quickly gives rise to a series of alterations to numerous trains. Similarly, delay to one train can cause delays to a whole group of trains.

Conclusions.

Intensive operation in stations and use of stock obviously leads to the most severe demands as regards quality of rolling stock (careful and regular maintenance) and the quality of the remainder of the railway equipment as well as last but not least the skill of the staff.

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New S.N.C.F. equipment for automatic signalling at level crossings,

by J. WALTER,

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I. INTRODUCTION.

Level crossings — the « no man's land which is occupied alternately by road and rail — demands from both users strict discipline and methodical precautions, in order that the conflict of requirements should be free from danger. The urgent character assumed by the problem in recent years has led several countries to introduce, on an increasingly international plane, regulations applicable to all road vehicles. Under the same conditions, railway equipment must play its part, particularly as regards automatic signalling to warn road users of the coming of a train.

France has for a long time watched American tests with automatic signals, without taking part in the tests; during recent years, however, the application of such signals has been greatly developed. Technical problems have had to be resolved in special conditions, some of which caused numerous difficulties. They have provided experience of their value in various respects. Now that a relatively high number of installations have been made at various points and a fair proportion of them have been in service for a number of years, it is worthwhile to form some main conclusions. This article is designed not to discuss the mandatory aspect of the question, but to offer some technical considerations and indicate present progress.

In fact, even with this restricted aim, it is desirable to refer to the main regulations in force, since the technical equipment has been designed to comply with their requirements. This reference is all the more necessary as the regulations have been considerably modified since the start and this has caused serious technical difficulties because of the need to change from one condition to the next with the least possible delay and expense. We shall indicate in the following chapters the measures taken to keep to fixed programmes and provide some details of various improvements introduced to take advantage of recent technical improvements.

II. SEMI-INDICATORS AND SEMI-BARRIERS.

At the time when the S.N.C.F. decided to proceed with methodical tests with a view to establishing automatic signalling to announce the approach of a train to a level crossing, there was no universally accepted doctrine. In fact, the only important applications were in the U.S.A. where they offered great diversity and the warnings were far from uniform.

The S.N.C.F. in agreement with the Ministry of Public Works inclined towards a signal (fig. 1 and 2) in which the approach of a train was communicated to road users by a red winking light with a warning notice « Beware of trains — Danger » (1).

This notice, currently known as a « semi-indicator » was made up of two parts, not visible when no train was near as they were then edge-on to the road traffic. The automatic announcing device caused each of the sections to turn and when closed together

(1) See « Revue Générale », March 1949, article by Mr. R. LÉVI : « New automatic signalling equipment for level crossings ».

they formed a semi-circle on which the warning could be read. A bell signal was started, as well as the light and warning notice.

First fitted at Ervy-le-Châtel, on the Troyes-St. Florentin line, the installation was soon completed. In practice, it appeared beneficial to have, instead of a single red light, two winking red lights, on each side of the track, these could wink either simultaneously or alternately. As a

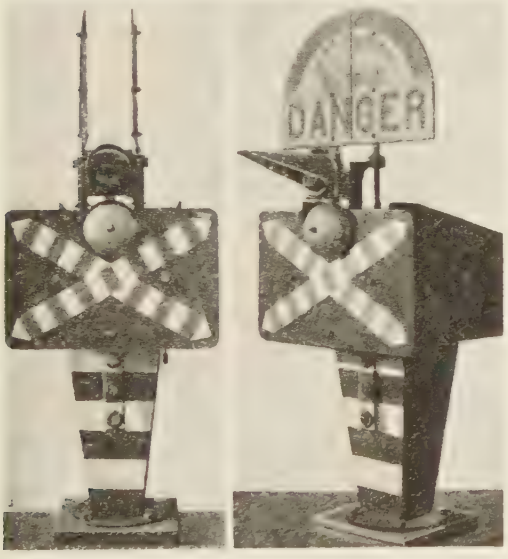

Fig. 1 and 2. — Ervy-le-Châtel type signal.
Signal cleared. Signal shown.

general rule, the two red lights were arranged horizontally between the warning notice and the St. Andrew's cross (fig. 3).

Signalling equipment of this kind, with one or two lights, calls for a very smal supply of energy because the winking lights are illuminated only for the passage of trains. This method of signalling was part of the St. Andrew's cross installation and included a warning in French.

International tendencies in this direction now are to use as far as possible a self-explanatory signal, visible at a great distance, universally understood, preferably to a text in the language of the country. Moreover, as a result of large scale experience in the United States good results had been obtained with movable arms, a sort of short barrier, hinged at the red lights (fig. 3). The arms are painted red and white and made light-reflecting; they are held vertical when no train is imminent and take a horizontal position when a train is approaching and remain so until the train is clear. Because the length of these arms is not equal to or does not exceed half the width of the road, the road vehicle can easily avoid the arms — called half-barriers — if they are lowered whilst the road vehicle is on the railway. The presence of these half-barriers cannot fail to attract the attention of a road user in a more imperative way than the folding warning notice.

Another improvement has been the separation of the two red lights, the arrangement adopted having the effect of showing them on each side of the road. In these conditions, when there is a bend in front of the signal, or when one of the lights is accidentally obscured, the other one remains visible.

To take advantage of these improvements, the S.N.C.F. in agreement with the Ministry of Public Works converted during 1955 to semi-barriers, some hundreds of two-part warning signs installed at level crossings.

The use of this automatic signalling at level crossings is subject to the fulfilment of certain conditions : essentially, there are the need for visibility sufficient for an observer on the road 3.50 m or less from the nearest rail at an operating time below an agreed amount. (We know that the « operating time » is the arithmetical product of the average number of railway journeys by the average number of road journeys using the level crossing during a period of 24 h.)

III. FUNCTIONING OF THE EQUIPMENT.

1. General.

The functioning of the equipment in its most simple form is shown in principal by

the diagram in fig. 4. (This diagram refers to single track equipment, with trains working in both directions.)

The passage of the train is denoted by electromechanical pedals, or electrical contacts which are controlled by small levers, moved by the wheels (or by the flanges). These levers are solid with pistons mounted in fluid carrying cylinders which have the effect of delaying the return of the lever to avoid shock by the repeated striking of successive wheels.

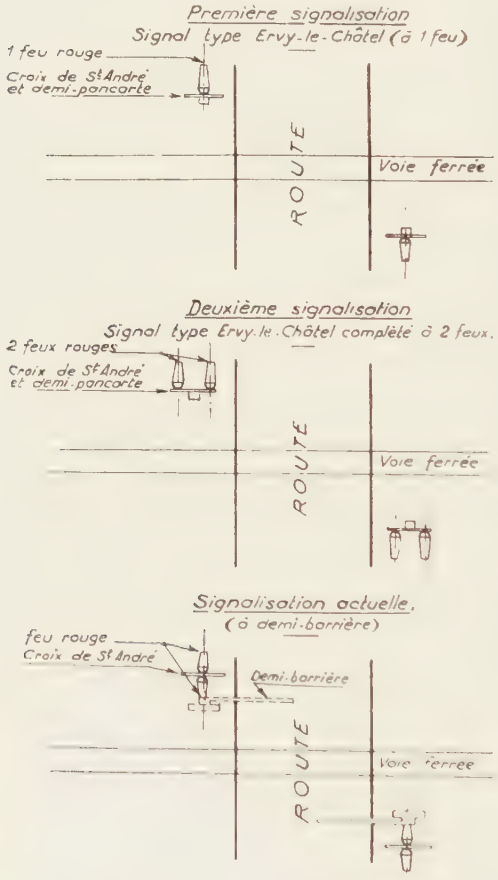

Fig. 3. — Development of road signals.

N. B. — Feu rouge = red light. — Croix de St. André et demi-pancarte = cross & warning notice — Route = road. — Voie ferrée = railway line. — Demi-barrière = half-barrier.

Why use these pedals, when every other country — in particular the U.S.A. uses only track circuits ?

If the S.N.C.F. use pedals — these are in fact electromechanical pedals — it is because in the equipment programme, level crossings suitable for the new automatic signalling were located for the most part on lines used by light railcars which are not certain to operate track circuits. The S.N.C.F., it is true, did some time ago introduce track circuits which provided a high degree of reliability for de-exciting track relays when such vehicles, even very light ones, passed over them (1). At the beginning, however, this track circuit was used in station areas. Additional experience would be necessary before extending its use further. In addition, this track circuit requires, in practice, a supply of current from the industrial mains which is not always available at level crossings. Finally, especially on single lines, the automatic warning of approach with track circuits still includes, in the present stage of technical development, complicated apparatus which is not needed when pedals are used, the latter having very great adaptability particularly when the warning zones are near stations.

It can be mentioned that there are two types of pedals : one acting in exactly the same way for either direction of travel, the other acting in different ways according to the direction of the train passing over, this difference of operation being obtained by the action of two interlocking levers. On single tracks, it is generally the latter type which is used. It is manufactured by the « Société Industrielle de Liaisons Electriques ». The interlocking of the two levers is a vital part of the equipment. It can operate under the most difficult conditions, as a pedal of this type has satisfactorily passed a test with rolling stock running at 331 km/h (206 miles p. h.) during the world speed record runs. At the same time maintenance in a satisfactory condition needs careful attention. A series of improvements

(1) See « Revue Générale », September 1954, Paper on : « Progress in track circuits, using electronics ».

has provided a higher standard of operation. As no other devices meet the requirements with less maintenance, however — and many inventors have tried in vain to produce one — this type of pedal, simple and ingenious, must be considered the most suitable for the service required from the equipment in question.

reaches the first pedal, the relays are de-excited which causes the automatic signals at the level crossing to come into operation. When the vehicle reaches the second pedal, this causes the first or warning pedal to be re-excited provided the pedal control relay allows. Where, because of accident, the second, or clearance pedal has its lever

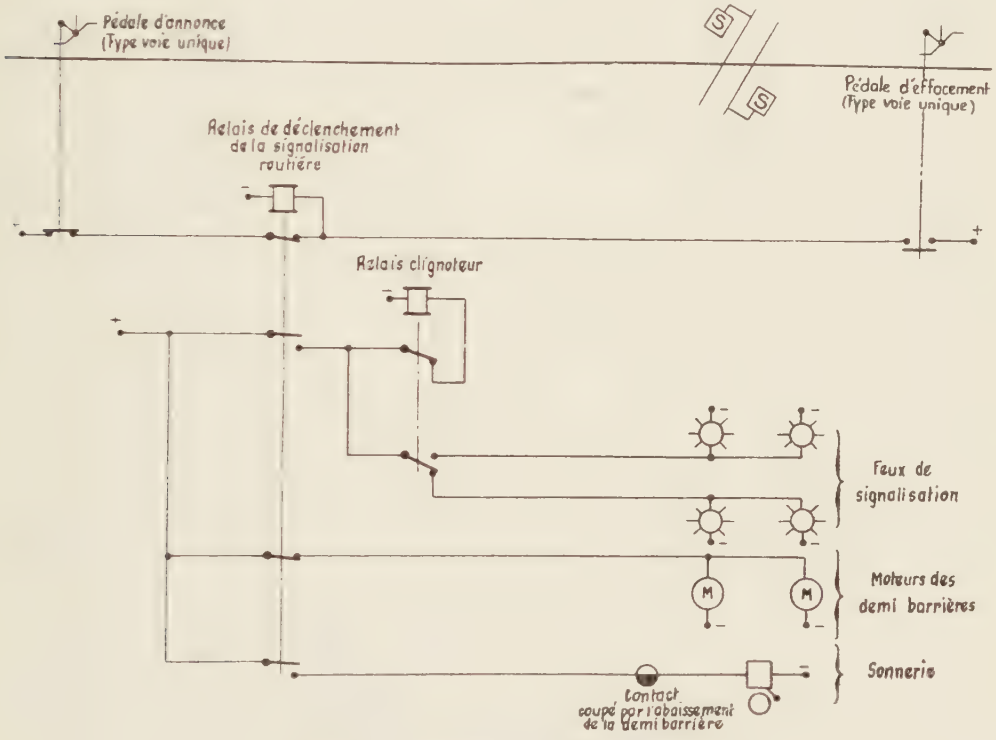

Fig. 4. — Automatic road signalling.
Simplified basic diagram (for one direction).
Single track used only by railcars.

N. B. — Pédale d'annonce = warning pedal. — Type voie unique = single track type. — Pédale d'effacement = clearing pedal. — Relais de déclenchement de la signalisation routière = road signal release relay. — Feux de signalisation = signal lights. — Moteurs des demi-barrières = barrier arm motors. — Sonnerie = bell. — Contact coupé par l'abaissement de la demi-barrière = connection cut by the lowering of the barrier arm.

2. Lines used only by railcars.

The diagram in figure 4 covers the case of a line used solely by railcars.

The principle of operation is very simple: when the first axle of the vehicle kept down, this relay would de-excite it and prevent re-excitation of the warning pedal to prevent any mishap. The road signal is cleared as soon as the warning relay is re-excited. A bell is rung to signal the lowering of the barrier arms and continues to ring

until the arms are in a horizontal position.

This system, which is very simple, is very suitable for a line on which railcars only are used. The clearing pedal then is located at a distance from the level crossing only slightly greater than the length of the railcars, about 50 m. In this way, the signal is cancelled as soon as the railcar has passed the crossing.

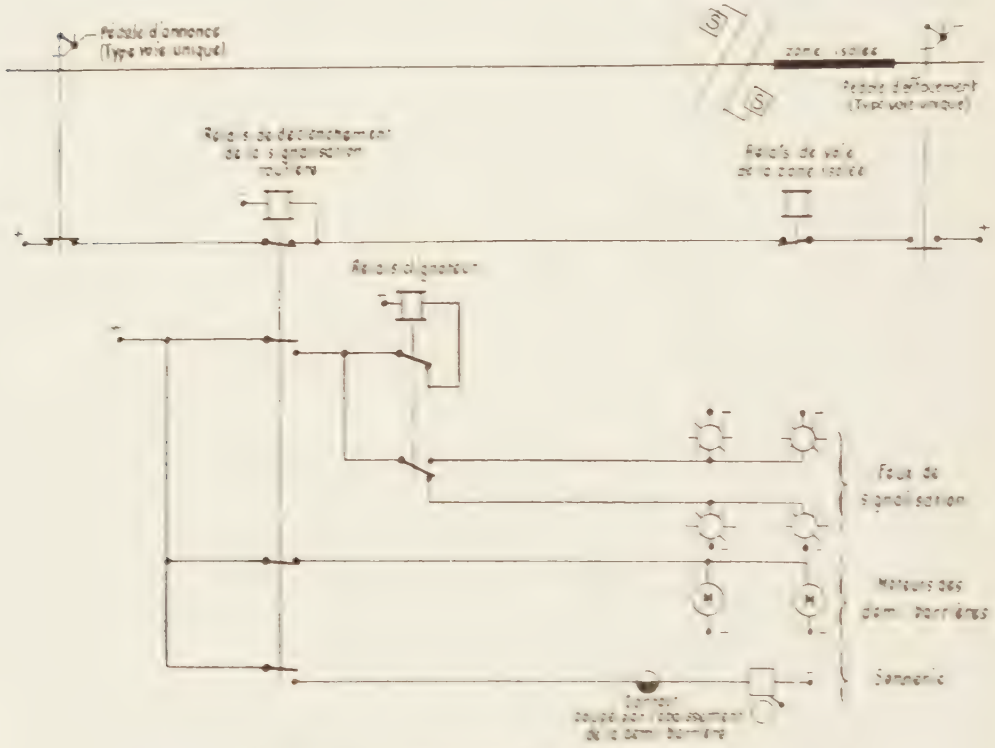

Fig. 5. — Automatic road signalling.
Simplified basic diagram (for one direction).
Single track line used by trains of varying lengths.
N. B. — Zone isolée = insulated area (see fig. 4 for explanation of other French terms).

3. Lines with insulated sleepers and non-welded track used for trains of varying lengths.

Where long trains run on the line, the above method is not suitable. The clearing pedal cannot be far enough away to cater for the full length of the longest train; in fact, for short trains, with such a disposition the clearance of the signal would be a while after the passage of the train and nothing is worse than systematic delays because they cannot fail to encourage in road users dangerous habits, by suggesting to them hazardous interpretations of the reason for continuance of a stop signal.

In certain countries, the difficulty has been countered by the installation of a short pedal with a time-log return, immediately beyond the crossing. This arrangement has not been adopted by the French authorities because it has a risk of accident

if a train should come to a stand whilst still foul on the crossing. The signal would not wait to be cleared because the pedal would have been depressed and would return to the open position. There would then be a train across the level crossing with no light to warn road users.

To meet this problem, the S.N.C.F. has adopted the installation on the track, in line with the roadway, of a device which confirms with certainty the presence or absence of a train. Wherever it is possible to insulate the rails from the sleepers and from earth, this is made a track circuit. When insulation of the rails is not practicable, the S.N.C.F. use a long pedal which has the same purpose as a track circuit.

The diagram in figure 5 shows the principle of this arrangement where use is made of the normal insulated track circuit.

In the absence of a train, the release relay for the road signal is excited, the lights are out and the half-barriers raised.

When a train operates the warning pedal, the auto-link relay is de-excited causing the lights to operate and the arms to drop. When the train reaches the insulated section the track relay is de-excited and the clearing pedal is in turn depressed. The road signal release relay is re-excited when the insulated section relay itself is re-excited and the clearing pedal is still depressed. In this way, the road signal is cleared when the train is clear of the crossing. In fact, the working diagram comprises a pedal relay with delayed de-excitation. If a train is accidentally halted on the crossing the track relay remains de-excited which ensures that during the whole of period concerned, the signals are operative. It must be added that the case of a light railcar or bad shunting would also give correct operation because, when the railcar actuates the clearing pedal, it clears the crossing. Even if the track relay was not affected by being run over, there would be no incorrect signal. A full and simple solution has thus been found to the difficult problem of automatic road signals at level crossings.

4. Lines with insulated sleepers and welded rails used by trains of varying lengths.

The arrangement mentioned above is perfectly suitable for a non-welded track on insulated sleepers. We know however that progress in track equipment is tending to the welding of rails over considerable lengths. A large part of the corresponding benefit will be lost if it is necessary to fit insulated joints at level crossings. This difficulty has been overcome by using the latest electronic signalling

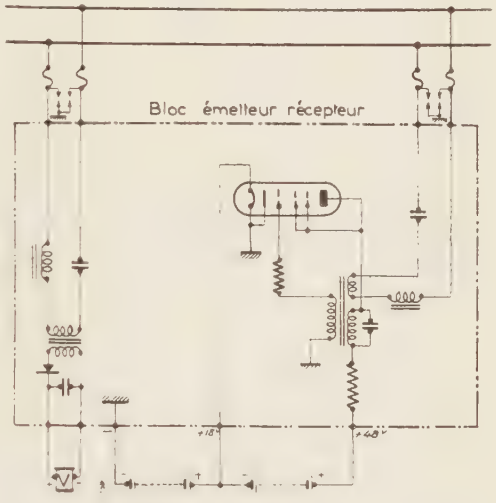

Fig. 6. — Track circuit without insulated joints. (Electronic track circuit at 8 700 cycles.)

equipment (1). A track circuit which does not need insulated joints has been used. Its effective length is reduced, but it is sufficient for the purpose of this installation. Supply to the track circuit is by an oscillator which provides current at a frequency of about 8 700 cycles. At this fre-

(1) Electronic track circuits are also described in the « Revue Générale », article of September 1954, mentioned earlier. This reference is to the product of the « Compagnie de Signaux et d'Entreprises Electriques ».

quency the track presents characteristics (1) such that shunting by a train is operative only when it comes near the insulated section. In the layouts used the distance between the « out-put » and « input » connections to the rail is from 20 to 30 m. The connections are, by definition, the boundaries of the actual section. A train is thus able to de-excite the track relay when it is a distance away from the nearer limit of the section of about 20 m. In the same way, the track relay can be kept in the open position after release of the far end of the section, when the train is at a distance from this far end of about 40 m. In these conditions, the pedal for resetting the warning relay at the level crossing is installed at a distance of at least 50 m from the trailing end of the sections fed at 8 700 cycles.

A transmitter/receiver set (fig. 6) comprises, on one hand an electronic oscillator with grid/plate coupling by a P.T.P. type 202 P electronic tube and a coil and condensers system in resonance with the track circuit at the frequency of 8 700 cycles; on the other hand, there is a receiver with a series resonant circuit opposing the passage of traction current, a booster transformer, rectifier and capacitator providing practically direct current to the track relay (2). The latter is a D.C. relay with one element and two repeater contacts. The current sources used are either lead accumulators (24 cells of 20 Ah) or sealed liquid cells. The diagram in figure 6 is for the latter type of feed.

It may be noted that the basic diagram in figure 5 must be slightly modified when a track circuit of 8 700 cycles is used. In effect, the insulated section in practice embraces the clearing pedal. It is thus convenient to re-excite the warning pedal by the return to rest of the cancelling pedal and the freeing of the insulated section.

5. Lines with non-insulated sleepers used by trains of varying lengths.

The equipment described above is suitable, either in the exceptional case of lines used solely by railcars or on lines used by trains of varying lengths where the track allows isolated sections.

There still remains the question of track where this is not possible, either because of metal sleepers or concrete sleepers which cannot be insulated.

A problem of this kind was set to the S.N.C.F. about ten years ago for equipping standard straight track on a single line. It was necessary in this case to control on the diverted track, the release of the points at the doubling point so that the signal could be off only when the crossing was effectively set. The « Etablissements Saxby » produced a pedal 18 m long — greater than the wheelbase of various types of vehicles — the pedal being depressed by the presence of a tyre on the rail. The pedal operated a switch, the contacts of which reported the

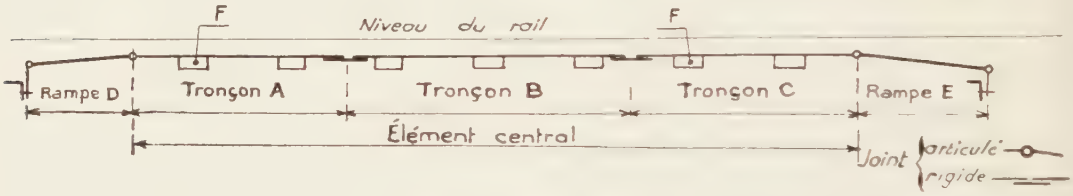

Fig. 7. — Saxby pedal.

N. B. — Niveau du rail = rail level. — Rampe = slope. — Tronçon = section. — Elément central = centre unit. — Joint : articulé, rigide = joint : articulated, rigid.

(1) As the section is not limited by the joints, the parts of the track on each side of it each form a resistance, the impedance characteristic having a modulus of 12 ohms and for argument 12°, for average, damp, ballast.

(2) A transistor assembly without electronic valve is also being tested.

presence or absence of a vehicle, in the same way as a track relay. This type of pedal was satisfactory in this case : it had,

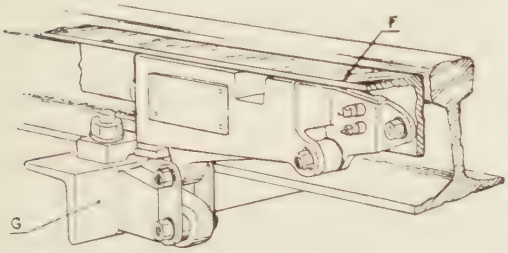

Fig. 8. — Pedal contactor box.

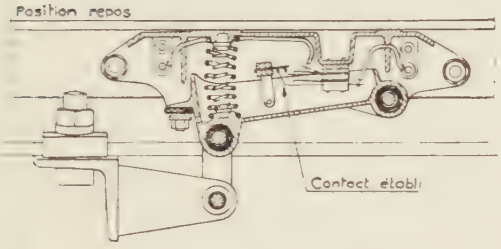

Fig. 9. — Electrical equipment of the pedal in free position.

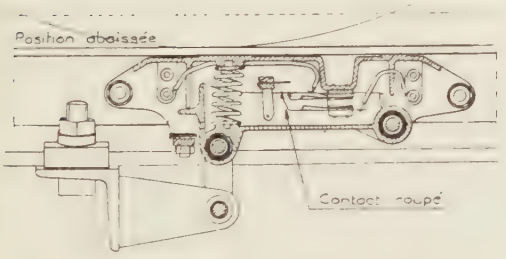

Fig. 10. — Electrical equipment of the pedal during passage of a train.

however, two drawbacks, firstly, it was designed only for slow speed running; secondly, it was operated by the wheel tyre which involves an element of unreliability from the relationship between the width of the tyre and its position on the head of the rail.

The same manufacturer, at the request of the S.N.C.F. and in collaboration with them, improved the equipment to overcome these defects. Firstly, the new pedal was fitted inside the rail and was actuated by the flanges. Secondly, it included articulated joints which allowed for the highest speeds at level crossings.

Figures 7, 8, 9 and 10 show the structure of the pedal and its operation. It comprises in the main :

— an angle-bracket composed of a centre unit in three sections, A, B and C with lengths of 6, 7 and 6 m respectively, rigidly assembled, and two end units D and E forming approach ramps and jointed to the ends of the middle unit;

— seven contactor boxes F carrying the middle unit which ensure its re-elevation by springing.

— nine supports G fixed under the rail shoes by bolts and clips; one end of the angle bracket is articulated directly on to a fixed part, the other end and the seven contactor boxes are linked to the other supports.

Each contactor box is equipped with two contacts. In these conditions, the electrical portion of the pedal comprises two parallel circuits each having seven contacts in series and opened when the central unit is in the raised position.

A pedal of this kind acts in the same way as the track circuit in figure 5. It can be used on a track having flat-bottom rails on cross or longitudinal sleepers. The spacing of the supports is at 3 m (1).

IV. MAIN TYPES OF HALF-BARRIER MECHANISMS.

During the first stage of equipment, level crossings, as already mentioned, were provided with signals incorporating warning notices. These notices were subsequently converted on the site to half-barrier arms,

(1) In the case of automatic road signalling at level crossings, such long pedals could be replaced by electronic track circuits of suitable frequency (actually much higher even than in the case mentioned), as soon as tests now in hand by the S. N. C. F. are completed, these deal with the installation of track circuits on lines without joints, event where the sleepers are considered non-insulating.

as described in the following paragraph. At the same time, this conversion, which gave rise to some tricky problems, could not be made for every length of barrier arm. It was possible only when the length of the arm to be raised and lowered was less than a specified limit of 2.30 m. In practice, this restriction caused no difficulty because the first level crossings provided with automatic signalling were generally on narrower roads. Special arrangements, described later, were taken to keep the movable arms as light as possible. The converted fittings form what it is convenient to call « light weight barriers ». Six hundred and forty seven level crossings are fitted with this type.

Another design of light weight barrier is that by Mr. Desvaux, Engineer of the Ouest Region, manufactured by Saxby. This is operated by hydro-electric mechanism on the following principles : each barrier arm is raised by a hydraulic ram which also acts as a brake when lowering the arm. The fluid under pressure is fed to each of the two rams by a single rotary pump fixed to the shaft of a low-voltage D.C. motor. The retention of the two barrier arms in the raised position is controlled by an electro-valve of high sensitivity and low consumption working by gravity. One hundred and thirty crossings are fitted — or about to be fitted — with this type, which has a very low consumption of energy. So far it has

Fig. 11. — Level crossing with automatic signals and half-barrier arms.

only been used for short barrier arms. Trials are in hand for extending its use to longer arms.

For medium and long arms — 3 to 7 m use has been made of electrical equipment provided by « Alsthom » or by « Hillairet »; the total number of crossings fitted under this headings is about 225.

The mechanism of these is, in the main : an electric motor, a cut-out, a contactor and reduction gear. The contactor registers and repeats to the motor the orders received from the control relay. The cut-out positions itself with the movement of the arm. The beam has a counterweight which tends to return it to the horizontal position in the absence of current.

The sequence for times of operation have to fulfil the following conditions :

For the fastest train, between the time of warning and the start of the arms lowering, a time log of 5-8 seconds.

The time for lowering the arms is 10-12 seconds. The minimum time between completed lowering of the barrier and passage of the trains is 5 seconds.

Figure 11 shows a photograph of a level crossing equipped with Alsthom type barrier, medium length, driven by electric motor and gear train.

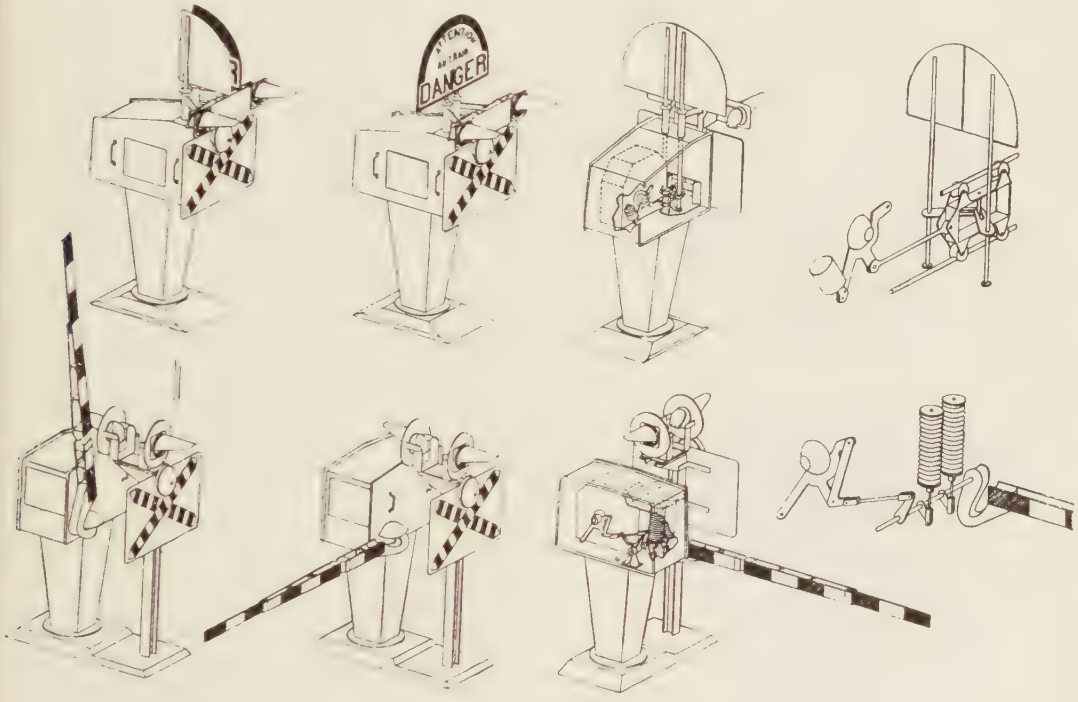

Fig. 12. — Conversion of warning notices to half-barriers by alteration to the mechanism.

V. CONVERSION IN SERVICE OF WARNING NOTICES TO HALF-BARRIER ARMS.

The mechanism used for the warning notices operated railway signal motors as used by the S.N.C.F. and supplied by the

Mors Company. The adaptation of this mechanism was done in such a way as to make it drive the half-barrier arms, reducing to a minimum the complication and cost of the job (fig. 12). The signal motor was retained but its position was changed, the motor being moved by 90° in relation to the pedestal. With the notice plates, the drive mechanism comprised a slide carrier controlling two opposing levers for simultaneous pivotting of each half of the notice plate. A counterweight reset the notice when the holding magnet was cut off from the supply.

To operate the arms, the motor performed the lifting by a rod and crank. In the absence of current to the magnet, the releasing of the equipment would have caused too rapid a fall of the arm. To overcome this, two air retarders are fitted.

Thanks to the careful workshop and site preparation, the change was made very quickly to allow the automatic signalling to remain in force, the interruption in every case being no more than a few hours.

VI. CONCLUSION.

To use terminology recently adopted in this respect, road signalling at level crossings is a *sequence automation*, of a very specialised type; such equipment is left out at a country site, exposed to weather; it must work with the greatest regularity; the few faults to which it is susceptible must always tend to give it a « stop » aspect, and never cancel such an indication; it must be adaptable to various requirements which may arise from progress in track equipment.

The equipments which have been described above have behaved satisfactorily over several years since the first applications. The number of level crossings with such equipment on the S.N.C.F. is now about one thousand. Their operation is satisfactory. The technical arrangements which have been described above have overcome the various difficulties at the cheapest cost.

Be that as it may, it cannot be doubted that new improvements will come along; the application of electronics to signalling particulary, trials with which are being carried out in the laboratories and on the track by the S.N.C.F., will bring further simplification and lighter construction.

The equipments described in this article are, however, an important stage in the development. That is why it is felt reasonable, at this time, to tell readers of this Bulletin the present position, without waiting the further developments.

[656 .257]

Matrices in the theory of interlocking,

by Dr.-Ing. Adelmo Davite.

(*Ingegneria Ferroviaria*, No. 3, March 1957.)

SUMMARY

The use of matrices can be shown to be useful in development and checking of interlocking for a main signal box. Somewhat complex installations can be subdivided into several parts and studied part by part. The features of each part can be represented by matrices; by multiplying the matrices one with another the matrix which represents the features of the whole installation can be obtained.

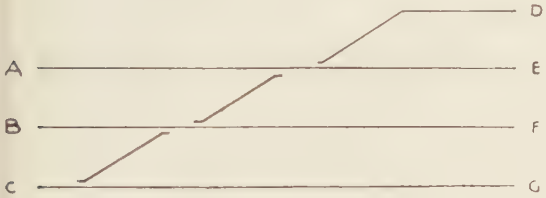

Fig. 1.

1. The development of interlocking for a signal box of moderate complexity can, on occasions, be somewhat irksome and can lead to errors of omission which may endanger operating safety.

The purpose of this article is to investigate simple methods which give a clear and orderly picture of the problem and which, when the scheme has been developed, enable the interlocking under consideration to be checked rapidly in order to eliminate the dangerous omissions already mentioned.

2. It will be recalled that, at the time when the first installations with route control levers were built, Moutier in conceiving his M.D.M. (minimum operation) system which uses the Pythagorean table, started from the basis that, if complete routes from one end to the other are taken, the search for conflicting routes is reduced to three cases :

a) routes with the same origin or the same destination, for example AD and AE (fig. 1);

b) intersecting routes like BD and AE;

c) tangential routes like AD and BE which conflict because they have sections of line in common (1).

Let us construct a double entry table of the Pythagorean table-type (fig. 2) and

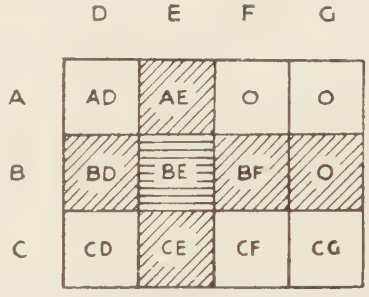

Fig. 2.

show on the ordinates the left hand ends of the routes and on the abscissae the right hand ends, and insert in each case the corresponding route (going from A to D, from A to E, etc.) writing 0 (zero) for the routes which cannot be set up.

(1) Cf. F. Tajani : *Trattato Moderno di Materiale Mobile ed Esercizio delle Ferrovie* (Modern Review of Railway Rolling Stock and Operation), 1933, Libreria Editrice Politecnica, Milan, t. II, chap. VII.

From simple inspection of the figure it can be seen that :

a) if a given route is considered, all the routes in the cross of items of which it is the centre have a point in common with the first route;

b) all the routes which intersect the given route are to be found amongst those items located below and to the left or above and to the right of the given route;

c) all of the routes below and to the right or above and to the left of a given route may be either tangential to or entirely independent of that route. We will demonstrate later how tangential routes can be distinguished from independent routes.

MOUTIER's findings will be taken as the basis of this study.

3. In a railway installation, a route may be considered as consisting of several sectional routes. From the point of view of investigating interlocking this sub-division is found to be useful because, by examining separately small sections of the installation, the possibility of error is reduced.

But, ultimately, what is required is to know what interlocking is needed between complete routes; the use of matrices enables one to go from the particular to the general. The term « matrix » means a table of items, for example, of numbers, placed in lines and columns (2).

A matrix is said to be of the type (m, n) if it has m lines and n columns; it is also said to be rectangular or square according to whether $m \pm n$ or $m = n$. A rectangular matrix can be turned into the square form by adding, in the lines or columns which are missing, items equal to zero.

(2) Cf. E. MONTÙ : *Matematica per tecnici ed ingegneri* (Mathematics for technicians and engineers), 1952, Editions Radiogiornale, Milan, chapter I, *Calcolo matriciale* (Matrix calculation), as well as A. ALBERT, Modern Higher Algebra, 1955, University of Chicago Press, chap. III : *Matrices*.

The table in figure 2 is a rectangular matrix of the type (3, 4) which represent the routes in figure 1.

To simplify the symbols, the routes which can be set up may be represented by 1, and those which cannot be set up by zero; the matrix in figure 2 is thus written as follows :

$$\begin{array}{c} \\ A \\ B \\ C \end{array} \begin{array}{c} \begin{array}{cccc} D & E & F & G \end{array} \\ \begin{pmatrix} 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 \end{pmatrix} \end{array}$$

By showing uninterrupted routes by 1 and interrupted routes by 0, a system is produced which is analogous to that used in the algebra of commutation electric circuits, where the contact set up may be shown by 1 and the contact not set up by 0 (3).

Let us now consider the installation in figure 3.

The matrix of the sectional routes of the first part is as follows :

$$\begin{array}{c} \\ A \\ B \\ C \end{array} \begin{array}{c} \begin{array}{ccc} D & E & F \end{array} \\ \begin{pmatrix} 1 & 0 & 0 \\ 1 & 1 & 1 \\ 0 & 0 & 1 \end{pmatrix} \end{array}$$

while, on the other hand, the matrix of the sectional routes of the second part is as follows :

$$\begin{array}{c} \\ D \\ E \\ F \end{array} \begin{array}{c} \begin{array}{cccc} G & H & I & L \end{array} \\ \begin{pmatrix} 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{pmatrix} \end{array}$$

It can easily be shown that the matrix of the complete routes of the whole installation in figure 3 is the product of the two partial matrices above if the product of two matrices is defined as the matrix obtained by multiplying the lines of the first by the columns of the second thus :

(3) Cf. R. RIGHI, *L'algebra dei circuiti di commutazione* (Algebra of commutation circuits), « Ingegneria Ferroviaria », January 1954.

$$\begin{pmatrix} a_{1,1} & \dots & a_{1,n} \\ \dots & \dots & \dots \\ a_{m,1} & \dots & a_{m,n} \end{pmatrix} \times \begin{pmatrix} b_{1,1} & \dots & b_{1,s} \\ \dots & \dots & \dots \\ b_{n,1} & \dots & b_{n,s} \end{pmatrix} = \begin{pmatrix} c_{1,1} & \dots & c_{1,s} \\ \dots & \dots & \dots \\ c_{m,1} & \dots & c_{m,s} \end{pmatrix}$$

the items of the resultant matrix being given by the formula :

$$c_{ik} = \sum_{j=1}^{n} a_{ij} \, b_{jk}$$

$$(i = 1, \dots, m; \quad k = 1, \dots, s).$$

It will be seen that the product is only definite if the number of columns of the first matrix is equal to the number of lines of the second.

In the case of figure 3 the result is :

$$\begin{array}{c} \\ A \\ B \\ C \end{array} \begin{array}{c} \begin{array}{ccc} D & E & F \end{array} \\ \begin{pmatrix} 1 & 0 & 0 \\ 1 & 1 & 1 \\ 0 & 0 & 1 \end{pmatrix} \end{array} \quad \begin{array}{c} \\ D \\ F \\ F \end{array} \begin{array}{c} \begin{array}{cccc} G & H & I & L \end{array} \\ \begin{pmatrix} 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{pmatrix} \end{array} = \begin{array}{c} \\ A \\ B \\ C \end{array} \begin{array}{c} \begin{array}{cccc} G & H & I & L \end{array} \\ \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 2 & 3 \\ 0 & 0 & 0 & 1 \end{pmatrix} \end{array}$$

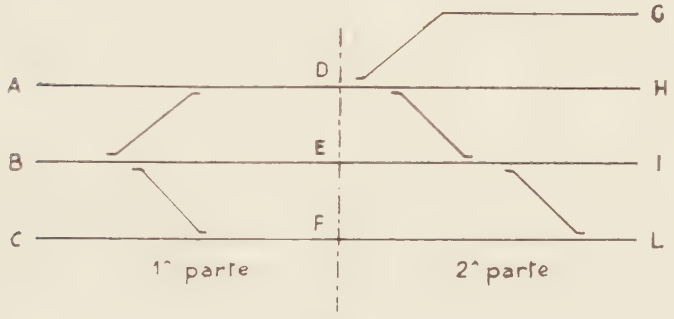

Fig. 3.

In the last matrix the number 2 in the second line of the third column shows that, between the points B and I there are two routes while the number 3 in the second line and the fourth column shows that between the points B and L there are three paths.

4. If it is wished to take account of the fact that routes may be available for running in one direction only (from left to right or from right to left), a situation which often arises in stations on the double track lines, the following points must also be borne in mind.

If the direction from left to right is shown by α and the direction from right to left by β and operation in both directions by ε, it is clear that :

— two consecutive sectional routes in direction α give a complete route in direction α; that is :

$$\alpha \cdot \alpha = \alpha^2 = \alpha;$$

— two consecutive sectional routes in direction β give a complete route in the direction β; in other words, that is :

$$\beta \cdot \beta = \beta^2 = \beta;$$

— two consecutive sectional routes in which one is two-directional ε and the other uni-directional α or β give a complete route in the direction α or β respectively; that is :

$$\varepsilon \times \alpha = \alpha; \qquad \alpha \times \varepsilon = \alpha;$$
$$\varepsilon \times \beta = \beta; \qquad \beta \times \varepsilon = \beta;$$

— two consecutive routes in opposite directions do not produce any complete route; that is :

$$\alpha \times \beta = 0; \qquad \beta \times \alpha = 0.$$

If the group of items α, β, ε, 0 is considered, it will be noted that ε is the item representing unity, that is to say the item which, multiplied by another item in the group, leaves it unchanged (4).

The double direction can be indicated by 1 instead of ε.

Further :

$$\alpha - \beta \quad \beta - \alpha = \varepsilon = 1.$$

Applying the foregoing rules, it is evident that the matrix of the complete routes in the installation shown in fiigure 4 is always the product of the matrices o the sectional routes :

$$\begin{array}{c} \\ A \\ B \\ C \end{array}\begin{array}{c} \begin{array}{cccc} D & E & F & \end{array} \\ \begin{pmatrix} 1 & 0 & 0 \\ \alpha & \alpha & \alpha \\ 0 & 0 & \beta \end{pmatrix} \end{array} \cdot \begin{array}{c} \\ D \\ E \\ F \end{array}\begin{array}{c} \begin{array}{cccc} G & H & I & L \end{array} \\ \begin{pmatrix} 1 & 1 & \alpha & \beta \\ 0 & 0 & \alpha & \beta \\ 0 & 0 & 0 & \beta \end{pmatrix} \end{array} = \begin{array}{c} \\ A \\ B \\ C \end{array}\begin{array}{c} \begin{array}{cccc} G & H & I & L \end{array} \\ \begin{pmatrix} 1 & 1 & \alpha & \beta \\ \alpha & \alpha & 2\alpha & 0 \\ 0 & 0 & 0 & \beta \end{pmatrix} \end{array}$$

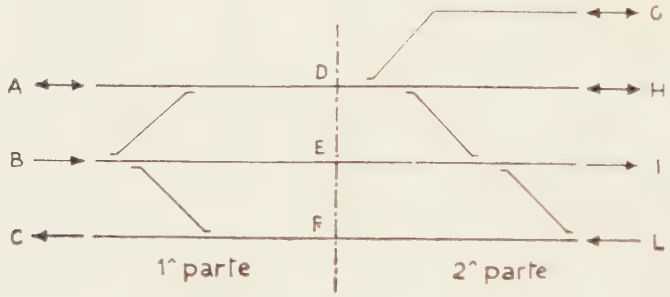

Fig. 4.

The coefficient 2 in the item 2α shows, as we have already said, the number of possible paths.

5. Let us now see how to take account also of the position of points covered by the different routes. We have seen that the symbol for a complete route (α, β, 1, 0) is the product of the symbols for the sectional routes of which it consists. On examining the points included in the complete route it will be observed that these are the sums of the points included in the sectional routes.

If the distinguishing numbers of the points included in the route are placed beside the route symbol (the numbers being underlined or not according as the points are set in the reverse or through position), the multiplication of the sectional route matrices, to obtain the complete route matrix, can also be carried out by multiplying the symbols, following the rules already indicated; the indices related to the symbols for the complete routes will be obtained by enumerating successively all the indices relating to the sectional routes.

For example :

$$\alpha_{\underline{1}} \times \alpha_{3-4} = \alpha_{\underline{1}-3-4}.$$

(4) See A. ALBERT : *Modern Higher Algebra*, chap. I : Groups and Rings.

The following equations are also obtained :

$$\alpha \times \alpha = \alpha; \quad \beta \times \beta = \beta;$$
$$1 \times \beta = \beta; \quad \beta \times 1 = \beta;$$
$$1 \times \alpha = \alpha; \quad \alpha \times 1 = \alpha;$$
$$\alpha \times \beta = 0; \quad \beta \times \alpha = 0.$$

Given that the symbols for the routes have different indices, instead of writing : $\alpha + \alpha = 2\alpha$, $\beta + \beta = 2\beta$, $\alpha + \beta = 1$, $\beta + \alpha = 1$, we must say that one can have one route or «alternatively» another. Representing the expression « alternatively » by the special symbol V, one would write for example : $\alpha_{\underline{1}-3-\underline{4}-5}$ V $\alpha_{1-2-4-5}$ to show that between two points a route in direction α can be set up through points 1 — 3 — 4 — 5 or alternatively a route in direction $\overline{\alpha}$ through points 1 — 2 — 4 — 5.

Let us consider the diagram plan in figure 5 in which is shown the numbering of points (points which are linked carry the same number because in practice they are operated together).

We then have the following :

$$\begin{array}{c} \\ A \\ B \\ C \end{array}\begin{array}{c} \begin{array}{ccc} D & E & F \end{array} \\ \begin{pmatrix} 1_1 & 0 & 0 \\ \alpha_{\underline{1}} & \alpha_{1-\underline{2}} & \alpha_{1-\underline{2}} \\ 0 & 0 & \beta_2 \end{pmatrix} \end{array} \times \begin{array}{c} \\ D \\ E \\ F \end{array}\begin{array}{c} \begin{array}{cccc} G & H & I & L \end{array} \\ \begin{pmatrix} 1_3 & 1_{3-4} & \alpha_{3-\underline{4}-\underline{5}} & \beta_{3-\underline{4}-\underline{5}} \\ 0 & 0 & \alpha_{4-\underline{5}} & \beta_{4-\underline{5}} \\ 0 & 0 & 0 & \beta_5 \end{pmatrix} \end{array} =$$

$$\begin{array}{c} \\ A \\ B \\ C \end{array}\begin{array}{c} \begin{array}{cccc} G & H & I & L \end{array} \\ \begin{pmatrix} 1_{1-\underline{3}} & 1_{1-3-4} & \alpha_{1-\underline{3}-\underline{4}-\underline{5}} & \beta_{1-\underline{3}-\underline{4}-\underline{5}} \\ \alpha_{\underline{1}-\underline{3}} & \alpha_{\underline{1}-3-4} & \begin{matrix} \alpha_{\underline{1}-3-\underline{4}-\underline{5}} \\ \mathrm{V}\ \alpha_{1-2-4-5} \end{matrix} & 0 \\ 0 & 0 & 0 & \beta_{2-5} \end{pmatrix} \end{array}$$

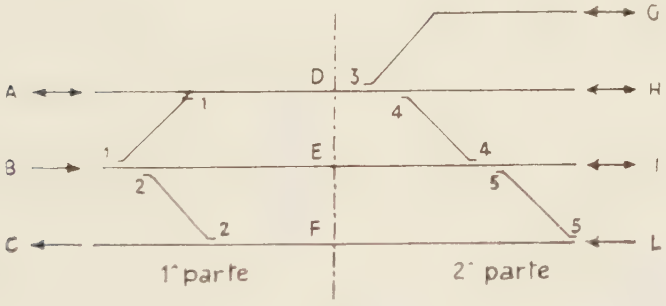

Fig. 5.

Consideration of this last matrix shows that two routes with their origin or their terminus at the same place, in other words, which are on the same line or in the same column, are mutually exclusive because they have at least one set of points in common, which has to be in normal position in one and reverse position in the other.

The same thing occurs with two routes which cross or, in other words, which are, reciprocally at the bottom left and top right. If the two routes cross at an intersection, as is the case in figures 6, 7 and 8, it is necessary to have recourse to lateral interlocking for the above conditions always to be verified that is to say to ensure that :

— for the route AD junction 12 is in the normal position;

— for the route BC junction 11 is in the normal position;
— for the route FI junction 13 is in the normal position;

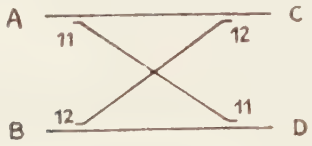

Fig. 6.

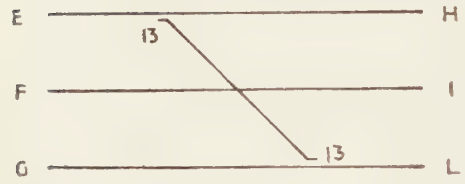

Fig. 7.

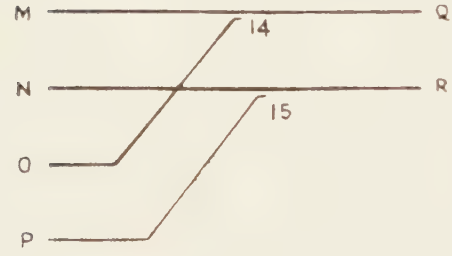

Fig. 8.

— for the route NR points 14 are in the normal position;
— for the route OQ points 15 are in the reversed position.

It will thus be seen that (provided that lateral interlocking is used as required) two routes placed reciprocally in the matrix in the bottom right and top left, are independent if their symbols have no common indices or have indices in common which do not conflict; otherwise they are tangential.

For example, if the last matrix considered is re-examined, it will be seen that :

— routes BH = $\alpha_{\underline{1}-3-4}$ and CL = β_{2-5} are independent because they have no index in common;

— routes AH = l_{1-3-4} and BI = $\alpha_{1-2-\underline{4}-5}$ are independent because the indices in common, 1 and 4, do not conflict with one another;

— routes AG = $l_{1-\underline{3}}$ and BH = $\alpha_{\underline{1}-3-4}$ are tangential because the indices in common, 1 and 3, are not in accord; in the first route, 1 is normal and 3 is reversed, while in the second, 1 is reversed and 3 is normal.

6. The use of the above method may be of value particularly for developing and checking interlocking installations which have several boxes in control of sectional routes, and a single box in control of signals controlling the complete routes.

Apart from the number of boxes, the method may be useful for somewhat complex installations; it then becomes convenient to sub-divide the installation into several parts, to examine and to check the interlocking for each part, to work out the partial matrix, and to derive from it the complete matrix.

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Air brakes . . .

. . . for high-speed ultra-lightweight passenger trains,

by T. H. Bickerstaff

General supervisor, Air Brakes, Atchison, Topeka & Santa Fe Railway System, Topeka, Kan.

(*Mechanical Engineer*, June 1957.)

A general description of five different approaches to brake equipment on ultra-lightweight passenger trains. None of these approaches meets with the general approval of all, and thus it is impossible to obtain agreement as to one right or correct scheme. Each manufacturer constructs his own system, introducing various points of emphasis which suit his own thinking. There is no alternative but to canvass each idea, compare it with others, and draw as reasonable a conclusion as possible. More definite judgments must wait for more careful analysis of the actual performance of each system.

Starting and stopping of trains are complementary factors in the problem of making time between stations; therefore it is evident that the best results can only be obtained where both factors are given due consideration. Generally, the starting factor is the only one fully considered, or at least the one most fully provided for. Better results can be obtained if both are considered and a more efficient brake system installed. The importance of the brake would be more fully appreciated if we could eliminate the impression that it is a safety device only, and realize that it contributes as much or more than the locomotive to faster and more frequent service. The same consideration should be given to its design and installation that is accorded to other parts of railway equipment.

Modern design requirements.

The early method of setting about to design a brake for a specific service, without thorough appreciation of the manner in which all the pertinent factors combine to provide a definite and usually predictable retarding force, cannot serve today. As understanding with respect to a certain operation becomes complete, new requirements are introduced. These call for further pioneering to provide new brake functions, or to extend the range of current equipment capacity. A knowledge of the behavior of fundamental factors to embrace new speeds, weights, and operating practices is also desirable.

Little can be said regarding braking factors that is not common knowledge — the governing factor being adhesion between the wheel and rail as well as between the wheel and shoe. Therefore the highest possible retarding frictional force that can be obtained with a brake would almost equal the adhesion of the wheels to the rail. With present rail conditions some sort of wheel-protection mechanism is a « must ».

Modern methods of automatically adjusting braking effort to take advantage of the substantially constant adhesive resistance at the rails use either an inertia governor, sensitive to retardation rate, or special governor element which approximates inertia-governor operation by recognizing the relationship between increasing retardation rate and decreasing speed. Of various forms, the wheel-slide detector is a device of prov-

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ed merit in the reliable performance of its function.

At the present time, five separate types of braking systems are in use on ultra-lightweight high-speed passenger trains. It is the purpose of this paper to briefly describe each system in general.

Jet Rocket.

The No. 26 brake equipment was developed especially for modern lightweight trains. It is an automatic type, designed to produce accurate responsive performance and flexibility of control, and is comparable to present-day electropneumatic straight air-brake performance on trains up to 500 ft in length. The No. 26 brake equipment requires only one pipe throughout the train for brake control, which makes it compatible with standard equipment. Proved and accepted automatic emergency features are retained.

The No. 26 control valve is relatively small in size, modern in design, and of lightweight construction. The design features include a service valve which combines the basic function of both the control and relay valves commonly used with standard D-22 brake equipment. This permits the mounting of all control parts on a single pipe bracket. When this equipment is used with a high frictional composition brake-shoe material which requires only one half to one third the force used with cast-iron shoes, additional advantages can be gained through the use of a smaller reservoir and brake cylinders. This permits considerable weight reduction in the air-brake control and the foundation brake equipment.

Technical progress has made possible a greatly simplified valve structure. Sensitive long-travel diaphragm pistons and O-rings are used. Ring leakage and the need for expensive lap-fitting are eliminated. Less skill should be required to maintain the control valve with this simplified construction.

For locomotive-brake equipment, the control valve is basically the same as that used for car equipment. In addition, a new compact lightweight 26-A locomotive brake valve has been developed to operate with the 26 control valve. With the 26-A brake valve, the degree of brake application is determined by the relative position of the handle in the braking quadrant. This is accomplished by a self-lapping and pressure-maintaining control portion of the brake valve. Small increments of brake-pipe pressure change are readily obtainable.

Electrical elements can be added to the No. 26 control equipment to provide electropneumatic operations for longer trains, if desired. This system includes automatic follow-up of electropneumatic service application in the event of electrical failure. The electrical elements pilot changes in brake-pipe pressure, thereby retaining the single-pipe system used with the automatic brake equipment.

Light wheel loads permit the use of single-shoe type brake with either metal or composition shoe on vehicles which normally would use clasp-type brake rigging. With the single-shoe arrangement, considerably less space is needed and simpler rigging is required with fewer component parts to maintain.

The unit-brake mechanism which can be used with this equipment incorporates the brake cylinder, slack adjuster, and required foundation brake parts in a compact space or enclosure (fig. 1). The levers or cam arrangement used to multiply the forces are greatly simplified. The compactness of these units made possible by the higher frictional performance of composition shoes permits a higher braking ratio than otherwise would be possible on lightweight trains where space is restricted.

The unit-brake mechanisms have higher efficiency than normal brake-rigging arrangements. Fewer levers and pins are required, thereby reducing friction losses. Individual unit-brake mechanisms are used with each brake shoe, insuring positive and uniform shoe clearance. They can be removed and replaced individually, greatly simplifying routine maintenance.

Owing to the semiarticulated type of design, only 16 axles are employed on a

12-car train — the first, third, fourth, sixth, seventh, ninth, and twelfth cars having only one axle, hence the wheel load of 9 000 lb on axles of the second, fifth, eighth, and eleventh cars and 7 600-lb wheel load on the remaining axles. The brake cylinders are 50 cu in. rotors chambers operating at 60-psi service pressure and 70-psi emergency pressure with 90-psi brake-pipe pressure. These develop 3 600 lb brake-shoe force on the heavy axles and 3 000 lb brake-shoe force on the light axles.

Fig. 1. — The unit-brake mechanism which can be used with the No. 26 brake incorporates the brake cylinder, slack adjuster, and required foundation brake parts in a compact space or enclosure.

The locomotive is equipped with the conventional 6-in × 8-in. UAH brake cylinders developing 5 050-psi brake-shoe pressure on wheels with a load of 30 000 to 33 000 lb.

Train « X »

Train « Xplorer » is equipped with a dual brake system designated as the LWE equipment. This equipment was designed to be operated in segregated service only. It cannot be operated as an automatic brake coupled to existing conventional equipment, and cannot be used to control cars with conventional automatic brake equipment because it has no trainline brake pipe through which conventional automatic brake operation is accomplished.

An electropneumatic straigth-air brake system is the basic control with a fully automatic brake system for conductor's valve brake application, simple train-stop functions, and break-in-two protection. Its automatic brake system also may be used as a protection in the event of failure of the electropneumatic system.

The electropneumatic straight-air brake system is built around a small-diameter trainline straight-air pipe (the term straight-air pipe » designates a control or actuating pipe that is free of air pressure during release of the brakes and has air pressure during brake applications). It con-

sists of a self-lapping brake valve with a control pipe connected to a master relay valve. This valve actuates a circuit breaker, the contacts of which energize or de-energize the trainlined electric circuits and coils of magnet valves throughout the train. These magnet valves function to admit a local

net valves throughout the train, produces rapid and flexible brake operation.

In the event of an electrical-system failure, the pneumatic-relay portion of the master relay valve and circuit breaker on the propulsion unit is actuated by the pressure differential thus created. This auto-

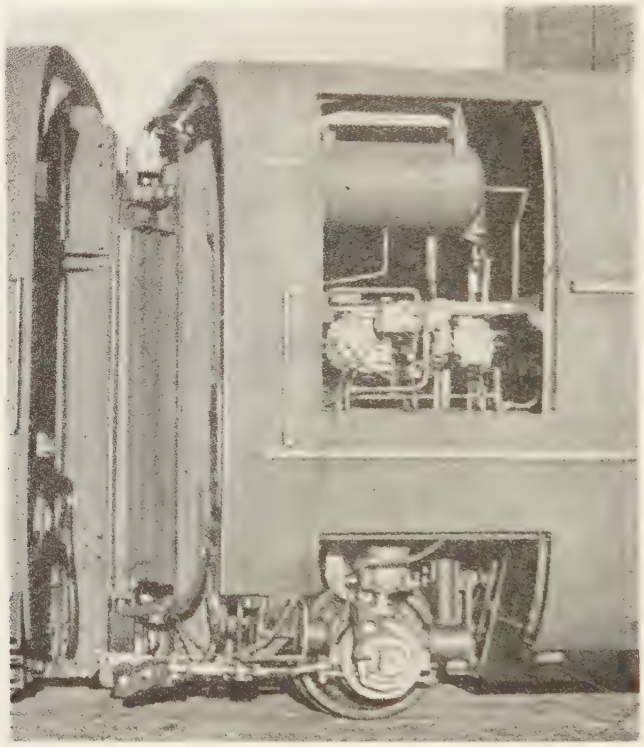

Fig. 2. — The « Jet Rocket » is a semiarticulated design. The axle at the end of the car is braked to the degree selected by the air-spring pressure at the end of the car, and compensates for the weight of the adjacent car.

supply of air to, or exhaust air from, the straight-air pipe which controls relay valves that admit air to, or exhaust air from, brake cylinders throughout the train. This type of system, incorporating a combination of small-diameter trainline straight-air pipes to be charged from local sources of air supply under control of electrically operated mag-

matically and promptly admits or exhausts air from the trainline straight-air pipe to accomplish the straigth-air pipe functions. Although subject to pneumatic lag caused by the feeding of a small-diameter trainline straight-air pipe from one end only, the resulting brake application will be substantially of the same degree that would

have been obtained with the electrical system.

The fully automatic brake system depends upon a trainlined supervisory line which is used during electropneumatic straight-air brake operations to supply air to the car-supply reservoirs and to keep them constantly charged. Full automatic brake operation, initiated by conductor's valve or train-control devices, is accomplished by exhausting the supervisory line. Break-in-two protection also is accomplished by the breaking and exhausting of the supervisory line. A full automatic brake operation also can be accomplished at the brake valve by moving the brake-valve handle to its extreme right-hand position whereby the supervisory line pressure is depleted through a large capacity valve to atmosphere.

The necessary devices to provide an adequate towing brake have been included in the locomotive brake system for dead-heading the train in event of a motive-power failure. The towing brake consists of a triple valve and its auxiliary reservoir for actuating the pneumatic straight-air feature of the brake system and the charging of the reservoir from the towing locomotive. The brake pipe of the towing locomotive is connected to the supervisory-line extension by means of a hose and coupling. The supervisory line and its connected reservoirs are then charged from the brake pipe of the towing locomotive. Brake-pipe reductions by the towing locomotive actuate the triple valve on the propulsion unit being towed and supply auxiliary reservoir air to the control pipe which initiates the brake application throughout the train by the straight-air pipe system.

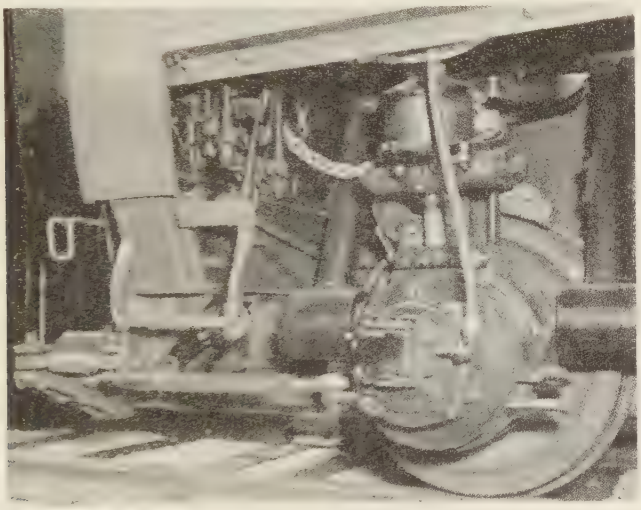

Fig. 3. — Train « X » is equipped with 7 × 3 1/2-in. brake cylinders which provide 50-psi service pressure and 80-psi emergency pressure.

Train « X », as well as the « Jet Rocket », is a semiarticulated type design (fig. 2). The axle at the end of the car is braked to the degree selected by the air-spring pressure at the end of the car. If the axle is not subjected to the added weight of an adjacent car, a differential relay valve develops brake-cylinder pressure which is 60 per cent of the control-pipe pressure at the relay valve. If the axle is subjected to the added

weight of a coupled car, the developed brake-cylinder pressure is 100 per cent of the control-pipe pressure.

Train « X » is equipped with 7-in. × 3 1/2-in. brake cylinders (fig. 3), which provide 50-psi service pressure and 80-psi emergency pressure. The supervisory line is set at 110 psi to develop the maximum brake-cylinder pressure mentioned above. Wheel loads of these cars are 15 150 lb on the heavy axle and 10 660 lb on the light axle, with a brake-shoe force of 4 320 lb on the heavy axles and 2 600 lb on the light axles during maximum braking.

The locomotive of Train « X » has a wheel load of 29 400 lb on the heavy (power) axles — and 20 000 lb on the light or trailing axles. A brake-shoe force of 3 460 lb is developed on the heavy axles and of 2 260 lb on the light axles, in the clasp-brake arrangement.

Aerotrain.

The air-brake system, as developed by Electro-Motive Corporation for use on the Aerotrain cars, is similar in principle to the vacuum-brake system used in many foreign countries, but differs in that air pressure is used in place of vacuum. The valvular components are, therefore, of a pressure design. The control portion and brake rigging are integrated and interdependent upon each other. This arrangement is essentially a straight-air brake with variations that permit the operation of two to twelve cars in multiple service. As in

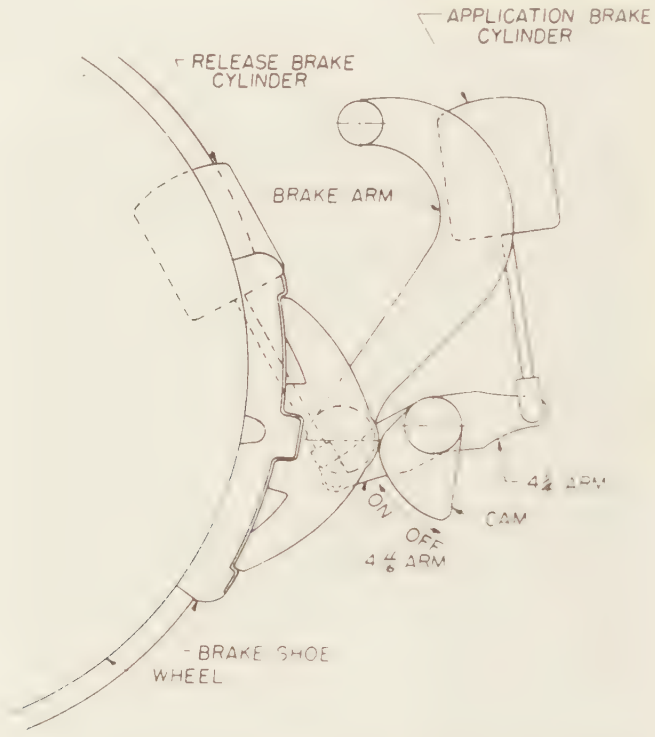

Fig. 4. — The brake rigging on the Aerotrain car consists of a nonmetallic brake block with suitable linkage between the opposing application and release cylinders.

previously described equipment, break-in-two protection is provided in the event of train parting.

Air is supplied to the car at 100 psi through a 1 1/4-in. supply line to a reverse relay, limit valve, relay valve, and to the conductor's valve and the back-up valve. The reverse relay regulates air to a cylinder through a spring-loaded check valve and volume reservoir, providing a predetermin-

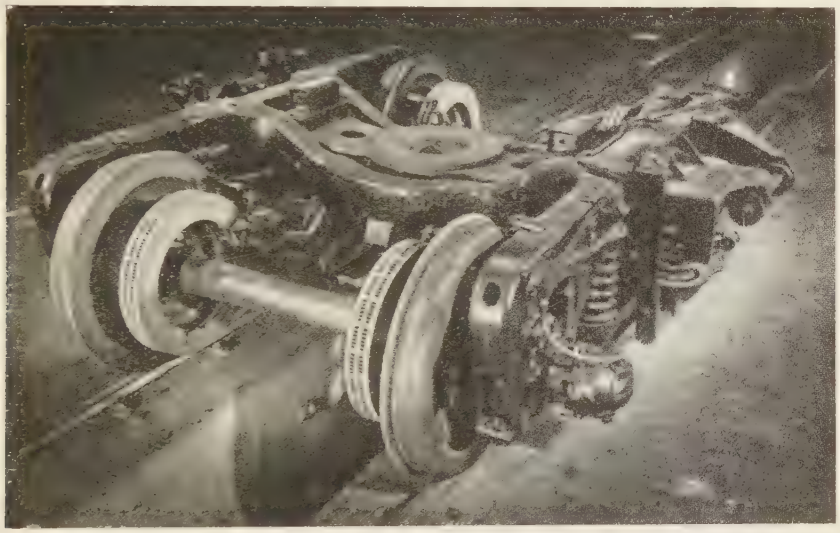

Fig. 3. — The « Tubular Train » brake equipment is similar to those previously described, as far as valvular parts are concerned, but the brake action is different, employing standard model « CF » Budd disk brakes.

ed pressure based on the retarding rate desired.

This cylinder is considered the application chamber. A second cylinder of the same area and opposed in direction to the application cylinder is charged to line pressure to release the brakes. The lever arm for the application cylinder is slightly less than that of the release cylinder to insure a release of the brakes upon recharge of the system.

When air is removed from the line by the control handle in the locomotive cab, air pressure is decreased in the release cylinder. The application piston then moves toward applied position an amount proportional to the reduction initiated. Thus the force on the shoes can be graduated « on » or « off », as required.

The brake rigging consists of a nonmetallic brake block with suitable linkage between two opposing cylinders. The application cylinder applies the brakes and the release cylinder, through a slightly longer lever arm, overcomes the force of the application cylinder, effecting a brake release. This arrangement provides pneumatic cushioning of the brake rigging in release and all intermediate points up to full application. This arrangement is shown in figure 4.

Many components of the locomotive equipment are standard items to other installations; therefore this description will cover only those items considered to be new developments which are not covered by existing publications.

There are three principal circuits in this

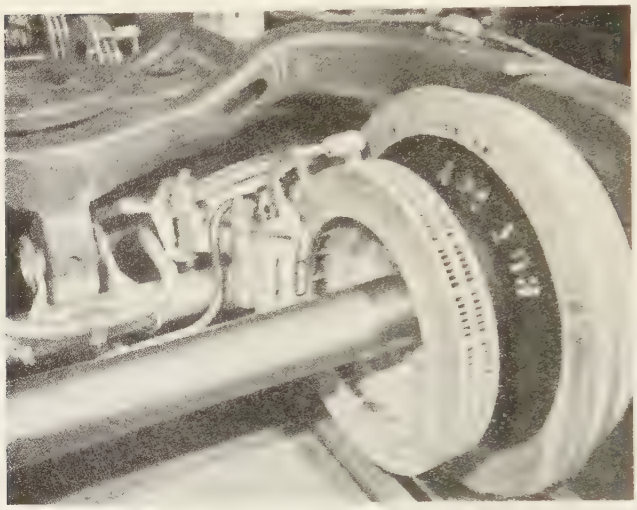

Fig. 6. — The standard « CF » Budd disk brake used with the « Tubular Train » brake equipment showing the assembly on the axle mounted inboard of the wheel. A complete carriage is shown in fig. 5.

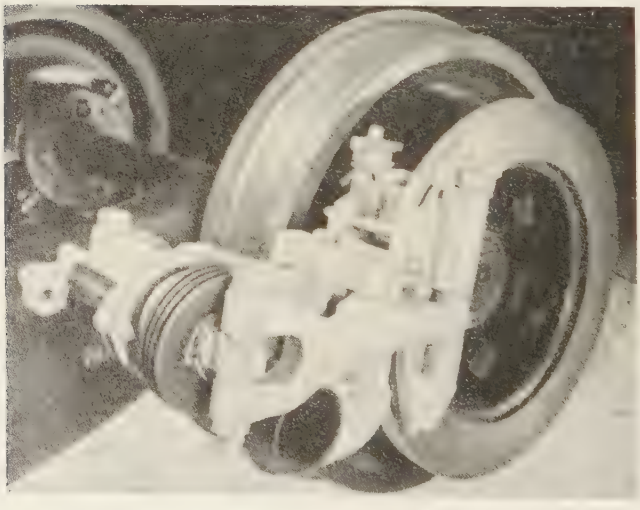

Fig. 7. — The « Pioneer III » is equipped with LWE brake equipment. Disk brakes of different design from that of the « CF » Budd are mounted on a tube welded to the truck side member and outboard of the wheels.

arrangement : the straight-air line, the supply line, and the conventional signal line. The straight-air line operates from 0 psi to approximately 20 psi in the service range, and from 16 psi to 24 psi when moving from service to full application. A straight-air application of 20 psi will develop 60 psi brake-cylinder pressure will be developed on the locomotive from application made at the conductor's valve or back-up valve in the train. In full application position, the straight-air pressure is increased to full value and a vent valve opens, resulting in the loss of the supply-line pressure. The

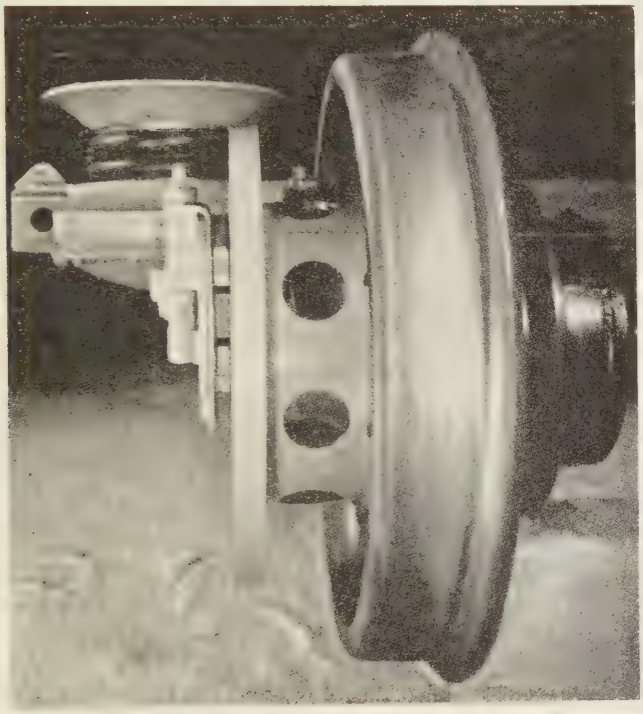

Fig. 8. — A solid nonventilated 23-in. disk is bolted to the wheel plate as part of the « Pioneer III » brake equipment.

effective brake-cylinder pressure in 3 to 5 sec on the train, and 45 psi on the locomotive.

The first or straight-air line is controlled by the S-26 brake valve, as used in the equipment on the « Jet Rocket » train. The handle of this valve controls a reducing valve which pilots a large-capacity relay valve. This relay supplies a straight-air line during a brake application through a cut off relay. The cut-off relay assures that loss of pressure operates the break-in-two feature of the locomotive and each car.

The second or supply line is fed from the No. 2 main reservoir through a feed valve set at 100 psi. Regulated pressure is furnished to the supply line through an application valve. This valve also acts to cut off the pressure and vent the supply line in the event of a full application of the brake valve or an emergency-valve application from the fireman's position. The supply

line furnishes air to the train brake system until 75 psi is reached. Above 75 psi, air is furnished to charge the ride-control system.

Provision has been made on the locomotive for shipment of the locomotive and cars dead in a train. This permits the automatic brake valve of the hauling locomotive to control the braking on the train. Uniform braking force exists on the locomotive and cars; therefore an independent brake is not provided. A parking brake for holding the locomotive has been provided, and is used wen making standing brake tests.

Tubular trains.

The « Tubular Train » brake equipment, as far as valvular parts are concerned, is similar to those previously described. The brake action is different in that the standard model « CF » Budd disk brakes are used (fig. 5 and 6).

The cars of this train have a ready-to-run weight of 88 300 lb and a fully loaded weight of 100 600 lb. The wheel load based on fully loaded weight is 12 575 lb. With an operating pressure of 110 psi brake pipe, brake-cylinder pressure of 36 psi in service and 60 psi in emergency are developed. With 60-psi brake-cylinder pressure a retarding rate of 2.65 mph per sec is accomplished based on fully loaded weight; a retarding rate of 2.85 mph per sec is accomplished based on ready-to-run weights.

Pioneer III.

The most recent development in ultra-lightweight passenger trains is the « Pioneer III » designed and built by the Budd Company.

Since the Pioneer III is equipped with LWE brake equipment, a description is not necessary.

Cars of this train have a fully loaded weight of 66 580 lb resulting in a wheel load of 8 322 lb. The braking level is set at, but not limited to, 2 mph per sec and is maintained, regardless of the weight of the car, within certain limits. This is accomplished by control of the brake-cylinder pressure in connection with the constant-leveling device incorporated in the air spring.

Again, disk brakes are employed but of an enterily different design. The brake is mounted on a tube welded to the truck side member (wheel piece) and outboard of the wheels (fig. 7). A solid 23-in. nonventilated disk is bolted to the wheel plate (fig. 8). Cylinders are cast-alloy aluminium, 4 in. in diam, and weigh approximately 12 lb. The brake-pipe or supervisory-line operating pressure is set at 110 psi. Service and emergency brake-cylinder pressures will be the maximum determined by the weight of the car as already described.

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What car reporting system is best for you?

The one that will do the job you want done. Here is a guide to today's car reporting techniques describing four basic systems, as well as a look into the future of car reporting.

Not long ago, a shipper telephoned a railroad freight traffic man asking if his car had arrived. The traffic man looked out his office window, and sure enough, the shipper's car was rolling by in a freight train.

" Your car's pulling into the yards now ", replied the traffic man, and with that he held the telephone receiver out the open window so the shipper could verify the fact.

Not all roads have such direct and simple means of telling shippers where their car is, but this road had a car reporting system, unique though it may be.

Let's look at this little more. This road had the basic ingredient of any car reporting system-communications. Here it was the telephone. Another railroad, which modestly says it does not have a car reporting system in the general sense of the word, does just about what our story tells. Each morning the trainmaster or freight agent scans the wheel reports and telephones shippers advising them of cars that arrived during the night which will be delivered that day. This practice started in one city and has grown to include all major terminals.

Communications the start.

Every railroad has the beginning of a car reporting system in its communications plant. Most roads have a printing telegraph network for messages and wheel report transmission.

Many roads use this yard-to-yard Teletype for transmitting wheel reports or train consists to provide advance switching information to yardmasters. There they have the " makings " of a car reporting system. It is but a small step to supply copies of these train consists to traffic offices or to send them into a central car service bureau or traffic office for distribution from there.

" I have a communications network. To set up a car reporting system, why do I need to spend a lot of money for all this other equipment I've been reading about—business machines, ' giant brains ', etc.? " You've posed a good question, and we'll try to answer it.

First, you want to make the most efficient use of your communications network. When you require it to carry the additional traffic for car reporting, which is more than just yard-to-yard transmission, you may have to expand your communications. Most railroads do. The amount of expansion depends upon how far-sighted your communications officers are. One road had only to add three trunk line circuits when installing a car reporting system. Another road installed nineteen trunk line circuits to carry reports direct to traffic headquarters. Most roads provide the additional circuits by installing carrier (" wired radio ") which eliminates the necessity of stringing line wires.

To make more efficient use of your communications network, you transmit only the information you need (including coding symbols to tell machines what to do). This is where business machines and punch cards may enter the picture. All roads agree on the type of basic information to be transmitted, such as car initial and number, but some roads desire to transmit more information in the wheel report than others. Up to this point in car reporting,

most everyone agrees at least as to the desirability of standardizing on information and form, although the specific symbols used may not be the same.

It's about how to prepare the information for transmission over the communications network that opinions differ. In all systems now in operation, except for experimental and test purposes, printing telegraph is used for transmission from yard-to-yard and to traffic headquarters.

Generally there are two schools of thought as to how the information should be prepared for transmission. One group favors punch cards and business machines and the other contends that Teletype equipment only is the most efficient. Either method accomplishes the desired result of mechanizing the handling of the car report information and eliminating unnecessary duplication of effort. Pro's and con's of the two are tabulated in the accompanying descriptions of the four basic systems.

Interchange of information.

Car reporting information from the yard offices goes, in many cases, to a central car service bureau. This central office usually does the sorting of the information on individual cars, and prepares the reports for sending to the traffic offices.

For clarity in this discussion, the four basic car reporting systems may be designated as follows :

PCT is punch card Teletype;
TRI is Teletype machine, Rock Island;
TMC is Teletype machine, C & O;
TMS is Teletype machine, Santa Fe.

The last three designations apply to systems developed on specific railroads. The PCT system, with minor variations, is used by several railroads, among them the New Haven, Union Pacific, Southern Pacific, New York Central and Erie.

Car reporting is almost universal in its application on railroads. What is not universal is compatibility of systems. That is, few roads can interchange car report information readily. One of the few systems in interchange is that of the Southern Pacific, including Texas & New Orleans lines, Union Pacific, and just recently the Chicago & North Western and the Milwaukee. Using the same form and language for car reporting information, an SP tape transmitted to Ogden will also be received at the UP yard office there. Thus the UP yardmaster has advance information as to cars coming to his road. This car report information is also passed along to the North Western and Milwaukee for cars destined to points on their roads.

One proponent of compatible car report systems, Dr. Fred J. Knight, says : " The railroads might go so far as to establish a cooperative car reporting service open to all railroads. Such a unified service might have fifty data processing centers strategically placed in the country. A nationwide system could make effective use of the new ' giant brains '. " (Railway Age, May 23, 1955, p. 29).

What could such a system do? Certainly what the individual systems do now — that is increase car loadings as a result of greater shipper satisfaction with faster service and reliable advance reporting of arrival time. And the second large benefit is a reduction in the investment in rolling stock, because of better utilization through better information about locations of empty cars. Also, time spent in yards is reduced because advance reporting enables yardmasters to plan their work better, making more effective use of yard tracks and better usage of yard crews and motive power.

Because shippers have advance information on car arrivals, they can load and unload cars promptly.

Here are the four basic systems.

Punch card tape.

In this operation, a punch card is prepared at the yard office for each arriving car. When a train is made up for departure, the cards are put in train order and then gang punched with the specific train information. Next they are run through a tabulator or collator which prints the train consist from the cards and

totals the loads, empties and tonnage. A copy is usually given to the conductor with the waybills.

Then the cards are run through a card-to-tape machine to produce a perforated tape for Teletype transmission to the next yard and to the car service bureau or traffic office headquarters.

At headquarters, the perforated tape is fed into a tape-to-card machine to produce punched cards. These are sorted either manually or by machine according to destination state or city. They are then processed to produce other cards with traffic office information only and these traffic office cards are grouped for sending to particular traffic offices. Again the cards go through card-to-tape machines to make a tape for transmission via Teletype. (Some roads send all car report information to all traffic offices, and they decide which information is of use.)

Some roads vary this process of supplying car reporting information to the traffic people. For example, the New York Central prepares a daily list of all car movements, the latest movement only being reported for an individual car. These listings are then train or air mailed each afternoon to traffic offices.

Other roads such as the New Haven, Union Pacific and Southern Pacific, Teletype car reporting information to their on and off-line traffic offices.

PCT's advantages. You mechanize the paper work in car reporting, both at the yard office and the central office. This improves operations, reducing repetitive paper work. Also, you materially reduce the time required at the central office to produce car information in the form for transmission to traffic offices. Another advantage is that you manually punch a card only once for each car; thereafter all work is done by machines.

... **On the other hand** considerable capital or rental money is required for each yard so equipped, i.e., initial installation costs can run up quite high. The equipment takes up considerable space, adding to the expense of costly additions to yard offices if they must be built for these machines.

Teletype car reporting.

TRI is perhaps the simplest system. On the Rock Island it requires only Teletype equipment at yard offices, and in the general telegraph office. Also included is an electronic sorting or switching system. The essential feature of TRI is that yard clerks originate the wheel report and prepare it in a special form, which includes special codes for selecting and directing the electronic sorter at Chicago. The wheel reports are sent via Teletype from the yard office to Chicago, where by code switching the consist is fed into the electronic sorter which records the consists on magnetic film. The equipment then « reads » the film and automatically feeds information about each car to repreforators which automatically punch tapes for the various traffic offices. These tapes are fed into equipment for transmission to the proper traffic offices.

The advantages. TRI requires only the use of Teletype equipment, which is familiar to all personnel. No additional equipment is required at yard offices. Clerks are readily trained to prepare the wheel report. At the general telegraph office, the only additional equipment is the electronic sorter. Here a minimum of attendants are required. Copies from the local traffic office can be obtained from the Teletype page printer.

... **On the other hand** accuracy of the system depends upon proper and accurate preparation of the wheel report in the yard office, and from then on there is relatively no check on accuracy. Some contend that business machine sorts and tabulators are good error catchers.

The C & O system.

TMC utilizes Teletype equipment at the yard office where a short piece of perforated tape is prepared for each car. This is filed with the waybill and when the train is ready to depart these tapes are fed into a Teletype machine to produce a long tape with the essential train information. This tape is then transmitted to a central telegraph office for relaying to a car movement bureau. Here the tape is run through a tape-to-card machine producing a punch card for every car in the train. These cards are then sorted according to destination, and given traffic office codes. Then they are run through card-to-tape machines to produce a perforated tape for transmission to traffic offices.

The advantages. Again, yard clerks work with Teletype equipment with which they are familiar. This equipment takes up less space than do business machines. Present personnel are able to produce the train consists readily, without extensive training. Only small addi-

tions of Teletype equipment are needed at yard offices, most of the present equipment being suitable for car reporting functions.

... **On the other hand** production of train consist tapes by Teletype is not as efficient as with business machines. Manual handling of small unit tapes (one for each car) slows down operations, according to some people.

Santa Fe has TMS.

In this system, yard office clerks prepare the train consists or wheel report by Teletype. These are sent via direct circuits to the car service office at Topeka, Kan. Here the incoming tapes are put through tape-to-card machines and the sorting for traffic office destinations is done by business machines. In this system a master card is kept for each car for one month. A quick check of the card will show the latest movement. Daily reports are sent via Teletype to on and off-line traffic offices so customers can be kept informed.

The advantages. Only Teletype equipment is required at the yard office. Another advantage claimed for TMS is that all business machines, as in TMC, are at one central office, where machine processing can be closely watched and efficiency maintained.

... **On the other hand** yard clerks must perform their work accurately, because they are responsible for putting the wheel report information in the correct order and arrangement in the wheel report forms.

2nd International Cybernetic Congress.

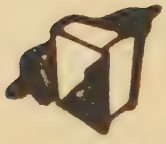
The Administrative Board of the International Association of Cybernetics, in its meeting at Namur (Belgium) on the 15th July 1957, has decided to organize at Namur, from the 3rd to the 10th September 1958, the 2nd International Cybernetic Congress.

The following subjects will be studied :

Information — Automation (Cybernetics applied to machines) — Automation (Use of automation in work organization) — Economic and social effects of automation — Cybernetics and Social Sciences — Cybernetics and Biology.

CONGRESS SECRETARIAT :

International Association of Cybernetics, 13, rue Basse-Marcelle, Namur (Belgium).



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In Portuguese.

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MONTHLY BIBLIOGRAPHY OF RAILWAYS[1]

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I. — BOOKS.

In French.

1957 **385**

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Paris, Libraire Plon. Un volume (14 × 23 cm) de 241 pages, avec 38 figures, 3 cartes et 2 planches. (Prix : 795 fr. fr.)

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Cours de mathématiques professé à l'Ecole nationale supérieure de l'Aéronautique et à l'Ecole nationale supérieure des Mines de Paris.

Paris, Masson et Cie, Editeurs, 120, boulevard Saint-Germain. Un volume (17 × 24.5 cm), de 916 pages et 363 figures, (Prix broché : 7 800 fr. fr., cartonné toile : 8 500 fr. fr.)

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Tarifs. 1) Relation entre les tarifs et les « Recettes et Dépenses » des entreprises de transports publics. 2) Diminution des dépenses par le service à un seul agent (tarification et perception). Rapport II du XXXII[e] Congrès International (Hambourg-Berlin, 1957) de l'Union Internationale des Transports Publics.

Bruxelles : Union Internationale des Transports Publics, 18, avenue de la Toison d'Or. Une brochure (21.5 × 27 cm) de 16 pages, avec figures et graphiques hors texte.

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Encombrement du trafic. b) Etude des plus récents moyens de transport (monorail, route guidée, chemins de fer suspendus, artère souterraine, tramways sous la chaussée, etc.) Rapport I du XXXII[e] Congrès International (Hambourg-Berlin, 1957), de l'Union Internationale des Transports Publics.

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Métallurgie à l'usage des ingénieurs.

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OFFICE D'EXPLOITATION DES TRANSPORTS COLONIAUX. (OTRACO.)

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[016. 385 (02]

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Integral tubular railcars. (2 200 words & figs.)

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1957 **625** .243

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Standard tank wagons. (900 words & figs.)

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Railway developments since the great war. 2-Achievements and prospects. (2 000 words & figs.)

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1957 **621** .436 (42)

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New turbocharger programme in Britain. (400 words & figs.)

1957 **621** .431 .72 (67)

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High-power « dual-transmission » shunters. (800 words & figs.)

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Automation takes command in modern classification yards. (2 100 words & figs.)

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Piggyback steps ahead as roads study coast to coast service. (1 000 words & figs.)

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Earnings key to future car supply. (800 words.)

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Hunslet Diesel-hydraulic locomotive for Northern Rhodesian copper mine. (400 words & figs.)

1957 **625** .142 (68)

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ROBERTSON (D.C.). — **Railway sleepers : Development and technical aspects in Southern Africa.** (600 words & figs.)

1957 **624** (68)

Railway Engineering, July, p. 28.

Twenty-four new bridges were built on S.A.R.'s longest double line. (400 words & figs.)

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High-speed bogie wheel lathe uses tungsten carbide tools. (400 words & figs.)

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Improved passenger accommodation in prototype coaches. (2 600 words & figs.)

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New bogies for Netherlands Railways electric stock. (800 words & figs.)

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Comparison between steel and aluminium passenger vehicles. (3 600 words & figs.)

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KUMAR (S.L.). — **Research on British and Western European railways.** (800 words.)

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High-speed Diesel-electric trains for international services. (600 words & figs.)

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German Trans-Europe express trains. (6 200 words & figs.)

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Diesel locomotives for British Railways. (2 200 words & figs.)

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Air conditioning for railcars. (1 900 words & figs.)

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Dutch-Swiss TEE trains. (2 400 words & figs.)

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Pennsy box cars should stay square. (2 600 words & figs.)

1957 **625** .241 (73)
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Rock Island builds... flat car with disappearing bulkheads. (300 words & figs.)

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8 500-HP locomotives power plants. (3 000 words & figs.)

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Wickham lightweight multiple-unit Diesel trains for B.R. (1 000 words & figs.)

In Spanish.

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Resultados de la explotación de los Ferrocarriles del Perú (Años 1954-1955). (500 palabras & cuadros.)

Transportes. (Madrid.)

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PRIETO (S.). — Los **transportes anfibios.** Una revolución en la técnica de los transportes. (2 000 palabras & fig.)

In Italian.

Giornale del Genio Civile. (Roma.)

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Giornale del Genio Civile, giugno, p. 434.
MATILDI (P.). — Risultati **di esperienze su travi inflesse in regime non di Hooke.** (6 000 parole, tabelle & fig.)

1957 **624** .2
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FUXA (U.). — Sul **tracciamento delle linee d'influenza dei momenti flettenti e degli sforzi taglianti nelle travi continue a vincoli non spostabili.** (1 000 parole & fig.)

Ingegneria Ferroviaria. (Roma.)

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Ingegneria Ferroviaria, luglio-agosto, p. 589 e 603.

A cento anni dall' inizio del traforo del Fréjus (1857-1957).

JANNATTONI (L.). — Dalla strada del Moncenisio alla **ferrovia del Fréjus.** (7 000 parole & fig.)

PISANO (F.). — **Gli studi, le invenzioni ed i lavori per la realizzazione del traforo.** (7 000 parole & fig.)

1957 **625** .285 (45)

Ingegneria Ferroviaria, luglio-agosto, p. 629.

MELANI (F.). — **Nuove automotrici termiche** per i servizi Trans-Europ-Express. (4 000 parole & fig.)

1957 **656** .235 .7

Ingegneria Ferroviaria, luglio-agosto, p. 654.

PANZARASA (C.). — Precisazioni sul **costo dei trasporti dei prodotti ortofrutticoli.** (1 200 parole.)

Politica dei Trasporti. (Roma.)

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Politica dei Trasporti, luglio-agosto, p. 420.

PATRASSI (A.). — Studio di **nuovi schemi per la rete metropolitana di Roma.** (3 000 parole & fig.)

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1957 **62**

La Ricerca Scientifica, luglio, p. 2065.

MARINO (A.). — **L'automazione nei suoi aspetti fondamentali.** (3 000 parole & fig.)

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1957 **625** .5 (06

Trasporti Pubblici, giugno, p. 701.

GRECO (G.). — **Il 1° Congresso Internazionale dei trasporti a fune.** (50 pagine & fig.)

In Netherlands.

De Ingenieur. (Den Haag.)

1957 **625** .13 (492)

De Ingenieur, nr 34, 23 augustus, p. Bt. 67 et Bt. 73.

JUNG (K.H.). — **Uitvoering Tunelbouw Velsen.** (3 000 woorden & fig.)

MEISCHKE (J.C.). — De **bruggenbouw bij de tunnelwerken te Velsen** volgens het Dywidag-systeem. (2 000 woorden & fig.)

1957 **621** .8

De Ingenieur, nr 37, 13 september, p. V. 63.

STEENMAN (J.A.). — Het **Wilson automatische transmissiesysteem.** (3 000 woorden & fig.)

Spoor- en Tramwegen. (Den Haag.)

1957 **656** .2 (4)

Spoor- en Tramwegen, nr 16, 1 augustus, p. 245.

LANDSKROON (E.P.A.). — De **Euromarkt en de Europese vervoerspolitiek.** (1 500 woorden.)

1957 **625** .2 (44)

Spoor- en Tramwegen, nr 16, 1 augustus, p. 248.

Het **experimentele « slinger-rijtuig »** van de S.N.C.F. (600 woorden & fig.)

1957 **385**

Spoor- en Tramwegen, nr 16, 1 augustus, p. 251.

Engelands bijdrage tot de **internationale uitwisseling van spoorweginformaties.** (2 500 woorden.)

1957 **656** .25 (8)

Spoor- en Tramwegen, nr 18, 29 augustus, p. 277.

KALEVELD (E.). — Het **beveiligingssyteem** bij de Zuid-Peruviaanse Spoorwegen. (1 500 woorden & fig.)

In Portuguese.

Gazeta dos Caminhos de Ferro. (Lisboa.)

1957 **656** .2

Gazeta dos Caminhos de Ferro, nº 1673, 1 de Setembro, p. 327.

O presento e o futuro dos Caminhos de ferro. Afirmações optimistas do Presidente da Associação dos Caminhos de Ferro dos Estados Unidos. (1 000 palabras.)

In Swedish. (= 439 .71.)

Järnvägsteknik — Statsbaneningenjören. (Stockholm.)

1957 **625** .28 = 439 .71

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BAGER (H.). — **Contribution to the question concerning the choice of the method of traction** (steam, Diesel, electric). (8 000 words, tables & figs.)

In Czech. (= 91.886.)

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[016. 385 (02]

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...Timber trestles with built-in fire protection. (600 words & figs.)

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Progress on the RF & P... Standards up but costs go down. (1 000 words & figs.)

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ARRILLAGA (M.M.). — **La reorganisación de empresas en orden a productividad** y el Ingeniero Director. (1 500 palabras.)

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MEREGALLI (G.). — La **situazione attuale delle Metropolitane nel mondo.** *(Continuazione.)* (15 000 parole, tavole & fig.)

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HEIJBLOM (Th.). — I. De **tunnel te Velsen en het wegverkeer.** (3 000 woorden & fig.)
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KRAAIJVANGER (E.H.). — **Vormgeving van beton in de architectuur.** (4 000 woorden & fig.)

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HALBERSTADT (H.A.C.). — **Postvervoer** bij de N.V. Nederlandsche Spoorwegen. (2 000 woorden.)

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De **Japanse Nationale Spoorwegen.** (1 500 woorden & fig.)

In Portuguese.

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SIMÕES DO ROSÁRIO (A.L.). — O **progresso d Caminhos de Ferro Espanhóis.** (2 000 palavras & fig

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Gazeta dos Caminhos de Ferro. (Lisboa.)

1957 **385** (09 (4
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DELAGE (E.). — Os **Caminhos de Ferro Francese** e a sua modernização. (1 500 palavras.)

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